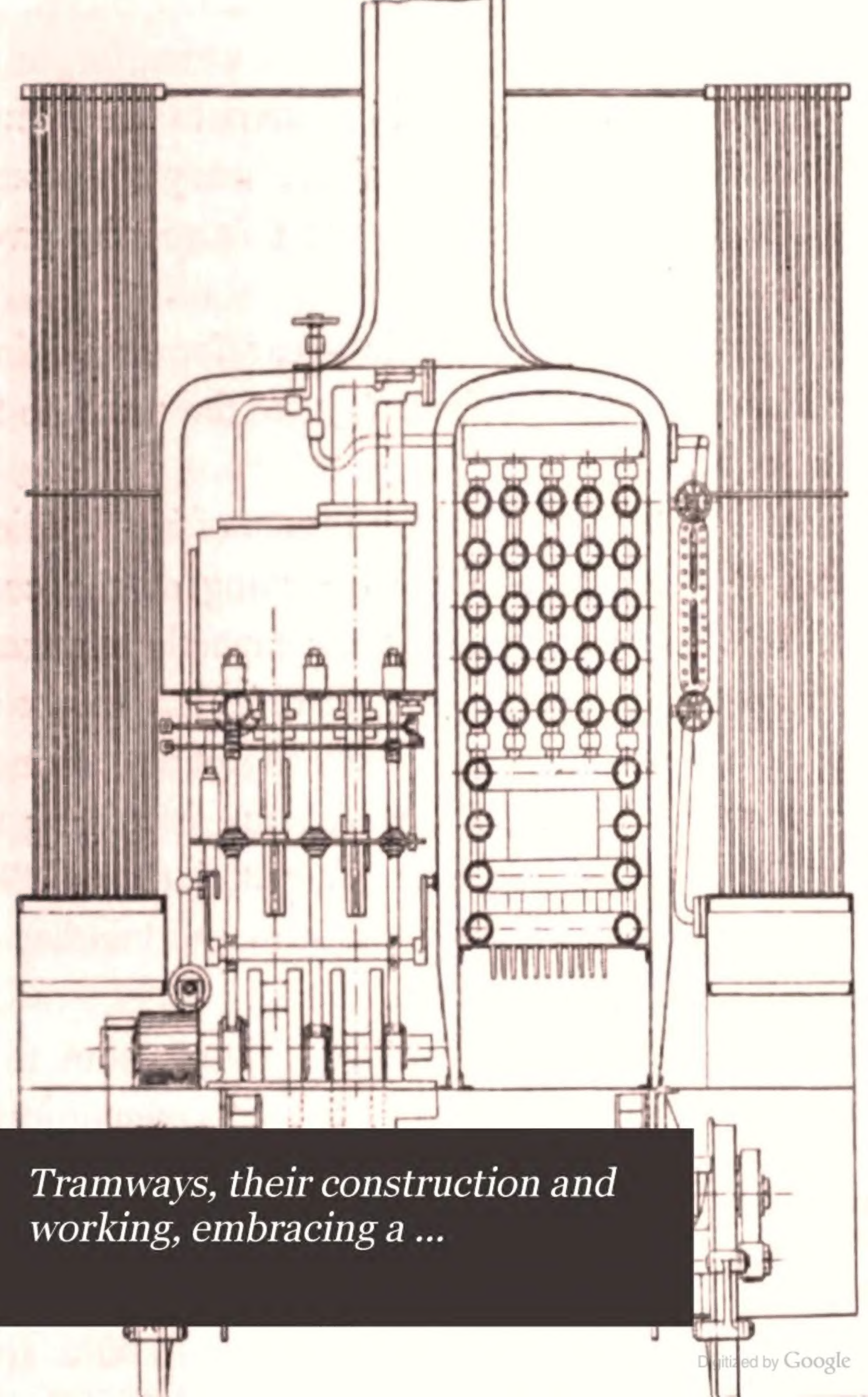

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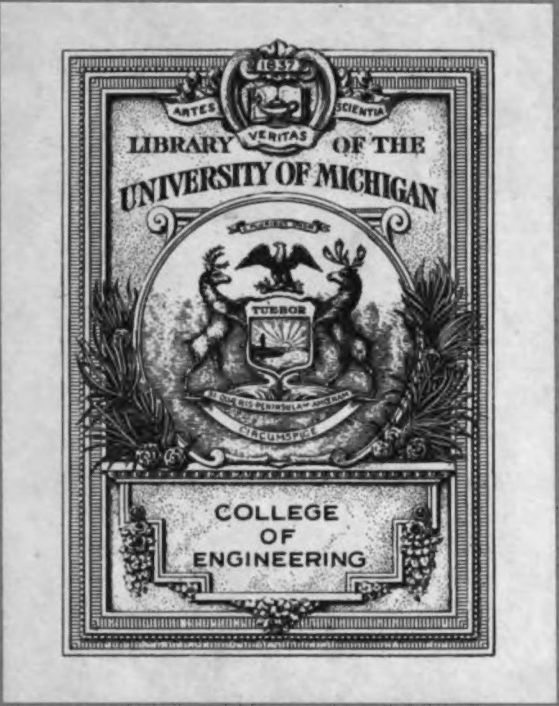
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THEIR CONSTRUCTION AND WORKING

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LOCOMOTIVES, CABLE TRACTION, AND ELECTRIC TRACTION)
A DESCRIPTION OF THE VARIETIES OF ROLLING STOCK
AND AMPLE DETAILS OF COST AND
WORKING EXPENSES

WITH SPECIAL REFERENCE TO THE

TRAMWAYS OF THE UNITED KINGDOM

BY

D.aniel KINNEAR CLARK, C.E.
M.INST.C.E., M.INST.MECH.E.

HONORARY MEMBER AMERICAN SOCIETY OF MECHANICAL ENGINEERS
AUTHOR OF "RAILWAY MACHINERY," "THE STEAM ENGINE," "THE MECHANICAL
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PREFACE

TO THE SECOND EDITION.

By the rapid development of Tramways during the sixteen years that have elapsed since the first edition of this work appeared, much experience has been gained, and much improvement made in construction. In view of the employment of mechanical traction upon a large number of tramways, the attention of engineers has been largely directed to increasing the strength of the way, for the purpose of carrying engines of the weight necessary for hauling power, as well as for adhesion. In the result, so far, metal ways, with girder-rails and simple connections, are the kind of structure at which we have arrived—on the principle, it may be supposed, of "the survival of the fittest." But we still await a settlement of the question of the best means of traction.

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To record analytically the progress that has been made in the design and construction of tramways, and in modes of traction by mechanical power—including cable traction, electric traction, and other motors—is one of the principal aims of the present volume. As in the first edition, so in the second, the work has been written with special reference to the Tramways of the United Kingdom, with incidental notices of work on the Continent and in America. A glance at the Table of Contents will be sufficient to disclose the extent to which an attempt has thus been made to cover the ground necessary for a comprehensive survey of the history and progress of tramways.

In addition to engineering matters, the accounts of various English tramways, and the capital cost and working expenditure of some of the undertakings, have been submitted to analysis. The propriety and desirability of uniformity of accounts, which is now enforced by the Board of Trade, was first recognised by the North Metropolitan Tramway Company. The beneficial effects of uniformity and lucidity of accounts are indisputable, not only for the instruction and satisfaction of investors, but for the guidance of promoters of kindred undertakings.

In regard to the statistical information given in the present volume, it should be mentioned that—the revision of the work for a new edition having occupied my attention over a considerable length of time, owing to other engagements—the details of particular undertakings have not in every case been brought down to the date of the last returns; but it is believed that in all cases the information given will be found such as to indicate with sufficient precision the points to which the attention of persons investigating the subject of tramways should be directed, and the quarters in which further inquiry may be usefully made.

In the APPENDIX, besides other matters of interest, there will be found a full abstract of the provisions of the Tramways Act, 1870; some account of the separate Parliamentary Enactments relating to Scotland and Ireland; the full text of the Board of Trade Rules for the guidance of promoters of tramway undertakings; and a full report of the judgment given by the House of Lords (July 30, 1894) on the question (arising under Section 43 of the Act of 1870) of the basis on which the value of tramway undertakings purchased by Local Authorities should be assessed. The various forms of Byelaws and Regulations affecting tramways, which have been issued by the Board of Trade, are also given.

In conclusion, I may express the hope—not only in regard to tramways properly so called, but also in respect of other forms of light railways, the introduction of which in country districts is now anticipated in the near future—that this new and enlarged edition of a work which has been so favourably received may be found of continued service to all engaged in the promotion, or construction, or management of such undertakings.

In carrying out the revision, I have availed myself of the best sources of information, including the Proceedings of the Institution of Civil Engineers and of the Institution of Mechanical Engineers, the Tramway Returns issued by the Board of Trade, and numerous official documents of the several companies whose lines are described or referred to; and I have to acknowledge with hearty thanks the assistance kindly rendered me in many quarters (some of which are indicated in the text) in furnishing needful particulars of information.

D. K. CLARK.

8, BUCKINGHAM STREET, ADELPHI,
LONDON: *September*, 1894.

PREFACE

TO THE FIRST EDITION.

TRAMWAYS have been developed by dint of sheer hard work and persistency, and they are now an accepted means of transport. urban and suburban, sanctioned by experience, approved and adopted by the public.

Unassuming and unobtrusive as they are, tramways have been the subject of a wide range of experience. By failures, engineers have discovered what would not do; and, as practical philosophers, they have, by induction, arrived at the conditions of efficiency. There exists a sentiment, which is somewhat prevalent, that tramway engineering is but a humble branch of the profession. The sentiment, born of self-complacency, is delusive. To tramways, it is true, Titanic arches, Acherontian tunnels, and Cyclopean engines, do not appertain. Nevertheless, tramways cost half as much as railways, and they earn more money by the mile; they have involved as much blundering as railways; like railways, they have exhausted reputations, and they have cost more than railways for working expenses.

The object of this book is mainly to place before engineers, capitalists, and financiers, a succinct analysis of the past practice and the present achievements in tramways in the United Kingdom, as works of engineering, and as money-making concerns. I have been materially aided in this work by the engineers of tramways, who have kindly placed their plans and specifications at my service; and by the secretaries and managers, who have supplied me with copies of their accounts.

I believe the results of these analyses will be found of essential service, in showing how the capital has been laid out, how the daily expenses are incurred, and in what directions economy of expenditure is to be effected.

Tramways will not take their fitting place in the systems of transport in the United Kingdom, until mechanical power is established in substitution for the power of horses. The employment of horse-power in the dire work of starting and dragging the ponderous cars in vogue is an element of barbarism, germane, it may be, to the primitive habits of oriental life, but very much out of place in a civilised country.

D. K. CLARK.

8, BUCKINGHAM STREET, ADELPHI,
LONDON: *March*, 1878.

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TRAMWAYS.

PART I.

ORIGIN AND PROGRESS OF TRAMWAYS.

CHAPTER I.

INTRODUCTION OF TRAMWAYS.

A TRAM, according to Nuttall, is the shaft of a cart or a carriage. It is also a local name for a coal-wagon, whence is derived the compound word "tramway" or "tramroad"—a road laid with narrow tracks of wood, stone, or iron, for trams or wagons.

In France, tramways were officially known as "horse railways" (*voies ferrées à traction de chevaux*). By the public they were known as "American railways" (*chemins de fer Américains*, or simply *l'Américain*). Finally, the English word "tramway" has become universally adopted in France.

A tramway, in the modern sense of the word, is a street railway, or a road railway, forming part of the roadway; such that the traffic of the street or the road, unaffected by the tramway, is free to circulate. It follows, as the principal condition of such free circulation, that the surface of the rails, whilst they are adapted for carrying flanged wheels, should be at the level of the carriage-way.

Tramways, for facilitating heavy continuous traffic, were, as may be imagined, more desirable in the days of no roads, or bad roads, than they are even now. They were laid, more than two hundred years ago, in the mineral districts of England, when coal was rapidly supplanting wood as fuel, for the conveyance of coal to the sea-coast for shipment. The difficulty of keeping the roads in repair—leading from coal-mines—may easily be conceived. Something of the condition of roads in the ante-macadam period may be witnessed to-day in the earth-roads of Egypt. These, after a heavy fall of rain, become seas of mud, and constitute formidable impediments to circulation, instead of facilitating it. Our forefathers were led to lay planks or timbers at the bottoms of the ruts, as a better contrivance than filling in stones. The inconvenience of the ruts, again, led to placing planks or rails of timber on the level surface. In 1676, tramways consisted of rails of timber laid "from the colliery to the river, exactly straight and parallel."

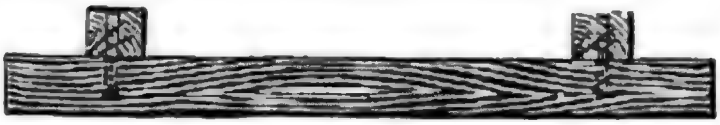

FIG. 1. Early timber tramways. Scale, $\frac{1}{24}$.

The rails, originally, were formed of scantlings of good sound oak, and were connected by sills or cross-timbers of the same material, pinned together with oak trenails, as shown in Fig. 1. The rails were 4 inches deep and 4 or 5 inches wide, laid parallel, 3 or 4 feet apart, in lengths of 6 feet. The cross-sleepers were 6 feet long by 4 or 5 inches deep and 5 inches wide, laid about 2 feet apart between centres. The rapid abrasion and wear of the rails, in consequence of the coarse construction of the wheels and the wear of the sleepers by the action of the horses' feet, led to the placing of an additional rail, Fig. 2, upon the first rail. This second rail

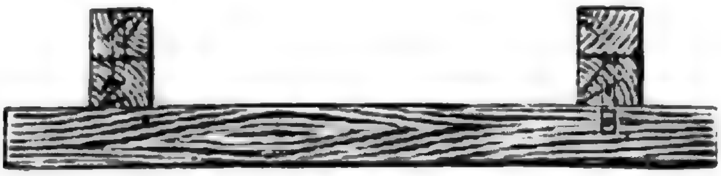

FIG. 2. Early timber tramways, with double rails. Scale, $\frac{1}{24}$.

became the wearing piece, and could be renewed with facility; whilst the increased depth afforded by it admitted of the covering of the sleepers by the soil, and their protection from the horses' feet. The wearing rails were of hard wood—beech or sycamore—6 feet long by from 4 to 6 inches deep. The under rails of the double way, at first made of oak, were subsequently made of fir.

It became a common practice to nail down bars of wrought iron on the surface of the ascending inclines of the road, where the draught was increased, in consequence of the greater wear of the timber. These bars, or rails, were about 2 inches wide, and ½ inch thick, and fastened to the wood rails by nails having countersunk heads. But the iron bars, not being stiff enough, were considerably bent when the trucks were loaded, and the resistance, according to Mr. Wood, was reduced but slightly below that of a well-constructed double wooden railway.

Nevertheless, a marked improvement in the performance of the draught horses followed upon the establishment of the tramway. The regular load of coals for one horse, on the common road, amounted to 8 bolls or 17 cwt., whilst, upon the tramway, the horse could regularly take a load of 19 bolls or 42 cwt. of coal.

Cast iron was first tried incidentally, as a material for rails, in 1767, by the Coalbrookedale Iron Company, who determined to protect their oak rails with cast iron, not altogether as a necessary expedient of improvement, says Mr. Hornblower, writing in 1809, "but in part as a well-digested measure of economy in support of their trade. From some adventitious circumstances, the price of pigs became very low: and their works being of great extent, in order to keep the furnaces in, they thought it would be the best means of stocking their pigs to lay them on the wooden railways, as it would help to pay the interest by reducing the repairs of the rails; and if iron should take any sudden rise, there was nothing to do but to take them up and to send them away as pigs." *

The iron rails were cast in lengths of 5 feet, 4 inches wide, and 1¼ inches thick, as in Fig. 3, formed with three holes, through

---

* Observations by Mr. Hornblower, in the Appendix to the Third Report of the Committee on Highways, 1809.

which they were fastened to the oak rails; "and very complete it was, both in design and in execution."

The tramway was developed into the railway by the employment of flange rails and edge rails of cast iron and of wrought iron, designedly elevated above the surface of the ground, upon new tracks laid out specifically for the formation of railways. But a reaction set in when it was found that railways wanted the needful adaptability to follow out the subordinate lines of traffic which occupied roads and streets. The convenient and unpretentious tramway was revived, and laid in streets and common roads, for the conveyance of passengers on the omnibus system. The revivals have, for the most part, been, like the primitive tramways, worked by horses. Nevertheless, in view of the success

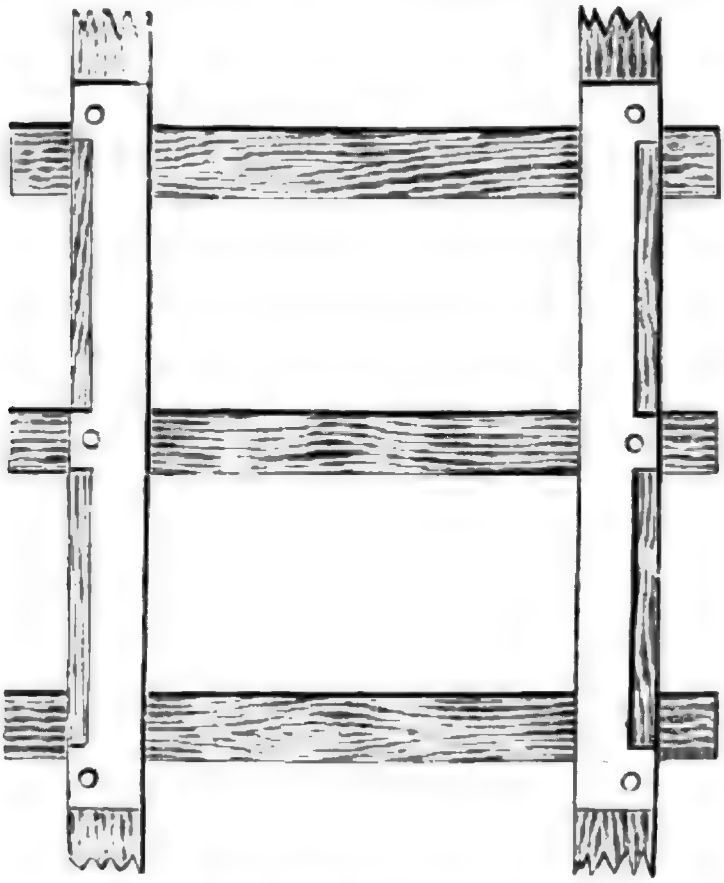

FIG. 3. Cast-iron tram-rails, by the Colebrookedale Iron Company. Scale $\frac{1}{24}$.

of the tramway system, as a mechanical fact, it may be expected that mechanical power will be generally substituted for horses.

The modern tramway was first employed in the United States, where it was urgently wanted, in consequence of the inferior condition of the streets and roads of the large cities. The first American tramway was the New York and Haarlem line, of which the first section, laid in the main thoroughfares to a gauge of 4 feet 8½ inches, was opened in 1832. But it was unpopular, and was for a time suppressed. Tramways, nevertheless, were revived in the same city about the year 1852 by the instrumentality of M. Loûbat, a French engineer, who recommended and laid down a tramway, consisting of rolled wrought-iron rails, laid upon wooden sleepers. The rails were constructed with a groove in the upper surface to guide the wheels of the cars, which were made with flanges, like those of railway carriages and wagons.*

Tramways were rapidly multiplied in New York, which owes much of its development to the tramways, the traffic upon which was of much more importance than that of the light wheeled vehicles used for ordinary circulation. Otherwise, the rails, which were formed with wide, gulf-like grooves, would not have been tolerated in the streets. The tramway afforded incalculable advantages, and it became an indispensable feature in the principal cities of the United States. The long distances to be traversed, the generally bad condition of the streets and roads, and the comparative scarcity of other vehicles, formed a combination of circumstances which forced the tramway-car into general use by all classes.

Habits were formed, and the irregularities of rails and roads were of less importance than they had been felt to be in Britain. The annexed sectional illustrations, Figs. 4 to 9, show the fearless manner in which the New York tram-rails were proportioned, combining obnoxious grooves with massive sections. An unsophisticated observer, struck by the proportions of these rails with the portentous grooves, described them as "rails which have a sort of iron gutter attached to each on their inside edge." *

---

* The rails laid by M. Loûbat, in Paris, hereafter noticed, were similar to those laid by him in America.

Mr. Charles L. Light, an English engineer, properly conceiving

NEW YORK TRAM-RAILS. Scale, ½ full size.

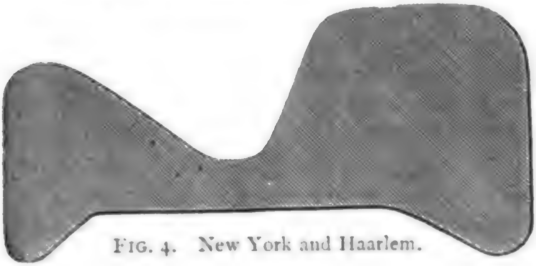

FIG. 4. New York and Haarlem.

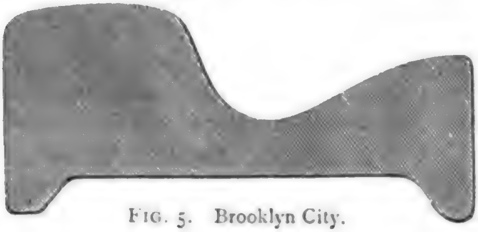

FIG. 5. Brooklyn City.

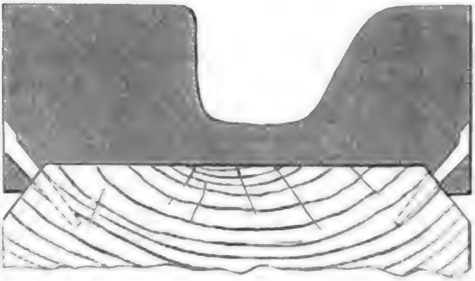

FIG. 6. New York, Second Avenue.

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* Letter of Mr. Longley, quoted by Mr. Beresford Hope, in his evidence before the Select Committee on Tramways, 1872. Mr. Peel,

that the great groove, or "gutter," in the New York rails was a great nuisance, devised and laid, in 1856—57, a less incommodious

NEW YORK TRAM-RAILS. Scale, ½ full size.

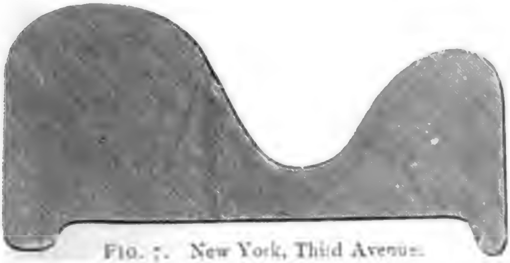


FIG. 7. New York, Third Avenue.

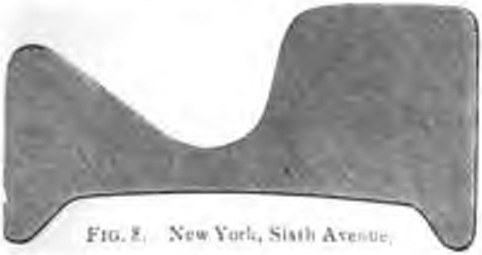


FIG. 8. New York, Sixth Avenue.

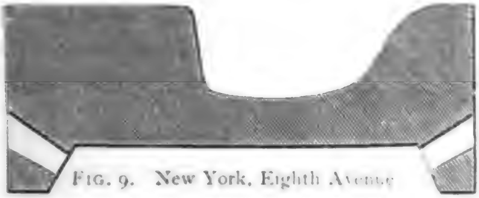


FIG. 9. New York, Eighth Avenue.

a member of the Committee, struck by the originality of the notion of a "gutter" alongside the rail, naturally inquired of Mr. Hope,—

"In comparing the New York system with that adopted in London, you spoke of an iron gutter as being a feature of the system ?"

Ans. "My correspondent is Mr. Longley, son of the late Arch-tram-rail in the streets of Boston, U.S., in which the depth of the groove was limited to ¾ inch, whilst the inner side of the groove was carried up with a flat slope, so formed that mud or small stones could be the more easily pushed away by the flanges of the car wheels. The groove was not so deep, and not so damaging to the wheels of ordinary vehicles, as the grooves of the New York rails.

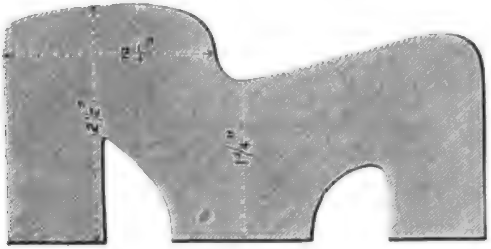


FIG. 10. Cast-iron rail, Boston, U.S., by Mr. C. L. Light. Scale ⅓.

bishop, who is very well known, and who happened to be in New York last year. I do not know whether you wish to challenge the social condition of my New York correspondent ?"

"Not by any means. But, as I understand, the iron gutter is not at all used in the English system ?"

Ans. "I do not suppose that any witness has contended that it is."

"But when you say that the New York system is characterized by iron gutters, and is therefore disadvantageous to the public, what is the inference you wish the Committee to draw ?"

Ans. "That the New York system has one more element of inconvenience in it than the English system."

As Mr. Hope himself said in his next answer, such sort of evidence is "a mere red-herring, very unfair and very untrue." Of such is history made.

Here is another bit of Mr. Hope's evidence: "Omnibuses, dangerous and disagreeable as they are, move in and out ; while a tramway cannot move in and out. . . . Mr. Train ran one of his lines, and had a station for his omnibuses under my window, and the noise, and the hallooing, and the row that went on was a great inconvenience, certainly." Such evidence was unanswerable.

The rails, Fig. 10, were of cast iron, in lengths of 6 feet and 8 feet, weighing 75 lbs. per yard. The ends of the rails were formed with dowels and cores placed diagonally, which, being interlocked, were designed to maintain the ends of the lengths of rail at one level. These rails, after several years' working, were replaced by rails of wrought iron.

In order to mitigate the inconveniences of the New York sections of tram-rail, a different sort of rail, Fig. 11, from which the groove was banished, though a ridge remained, was introduced in Philadelphia, and laid in Fifth and Sixth Streets, where it gave satisfaction. It consisted of a flat plate, 5 inches wide, formed with a raised ledge or step at one edge, standing ⅞ inch above the surface of the plate, without any groove. The plate was formed with a ledge or fillet at each side below, let into corresponding rebates in the upper corners of the sleepers, which were of wood. The weight was 46 lbs. per yard. The gauge was fixed at 5 feet 2 inches between the ledges to suit the wheels of ordinary vehicles, which could run on the lower flat surfaces. The type of tramway thus settled for Philadelphia in 1855, is shown in Figs. 12 and 13.

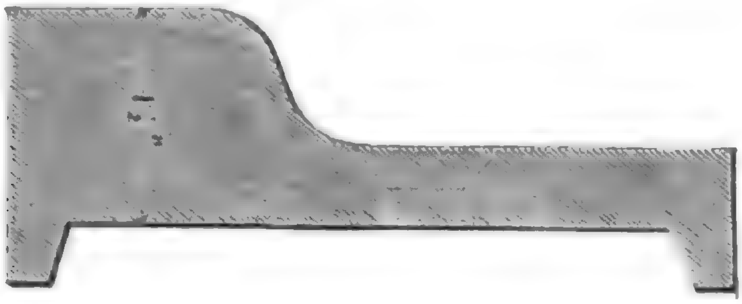
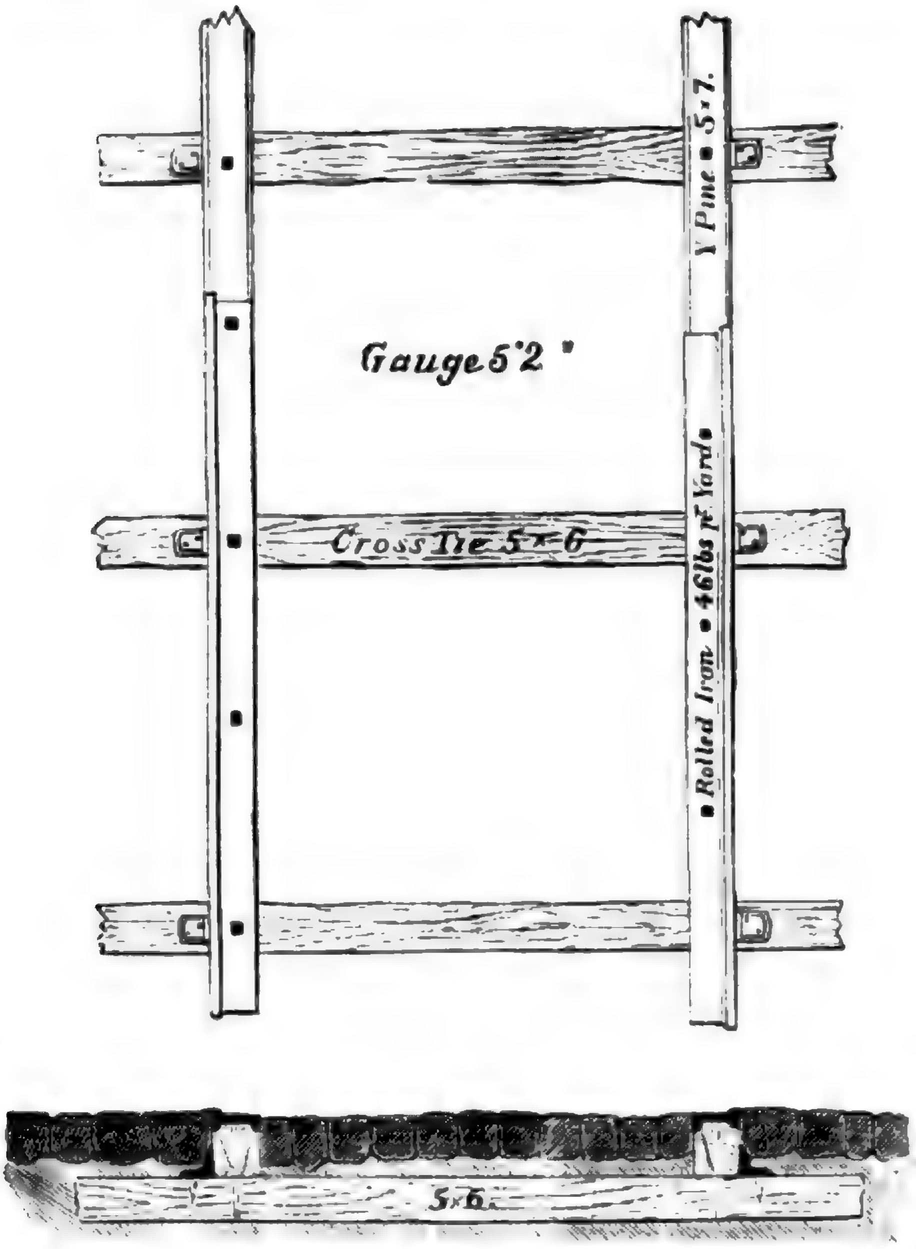


FIG. 11. Philadelphia step-rail. Scale ½.

The rails were laid on longitudinal sleepers of yellow pine, 5 inches wide and 7 inches deep, bolted down upon transverse sleepers, 6 inches wide and 5 inches deep, with iron knees to maintain the rails in gauge.

Following the principle of the Philadelphia rail, but adopting a greater width—8 inches—a similar rail, Fig. 14, was introduced in New York previous to 1860. It was better adapted for taking the wheels of ordinary vehicles, which varied considerably in gauge, whilst new vehicles of the ordinary kinds were made to fit the tramway.


Y Pine • 5×7.
Gauge 5'2"
Cross Tie 5×6
• Rolled Iron • 46lbs pr Yard •
5×6.

FIGS. 12 and 13. Philadelphia Tramways. Scale $\frac{1}{36}$.

But the wide tram-plate or step-rail incurs the objection that it does not afford a good foothold for horses, whether harnessed to tramcars or to ordinary vehicles. There is, besides, the general objection to the step form of the surface, in which, though the rise may never exceed an inch, the elevation is sufficient to cause a considerable degree of inconvenience to vehicles crossing the rails in an oblique direction in straining the wheels and the axles. The step-rail possesses, on the contrary, the advantage over the grooved rail that the flange of the car-wheel is always free, as there is no groove for the lodgment of obstructive pebbles and mud, whilst there is nothing to seize the wheels of ordinary vehicles.

The step-rail is in general use in the principal cities of the United States, where probably there is less of the light cab and omnibus traffic than what prevails in English cities and towns exposed to the action of the obnoxious step.

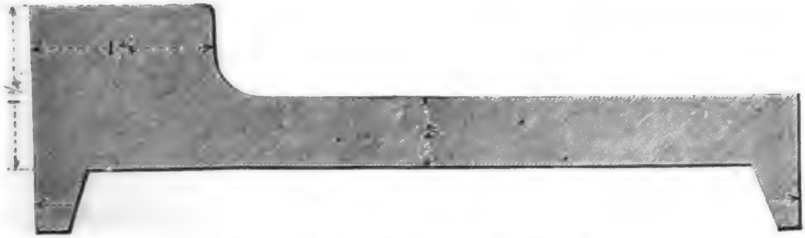


FIG. 14. New York step-rail. Scale ½.

Tramways have been widely extended in the chief cities of the Union. The gauge of tramways adopted, for the most part, in the United States is 4 feet 8½ inches.

The tramway system of Buenos Ayres, the principal city of the Argentine Republic, is a conspicuous example of the beneficial adoption of tramways in towns. There were, in 1872, in operation or in course of construction about 70 miles of tramway in that city, a greater mileage probably in proportion to the size of the place—which contains 200,000 inhabitants—than has been laid in any other city in the world. The extraordinary development of the system there is attributable in a great measure to the comfort, the cheapness, and the rapidity of tramway locomotion compared with the previously existing means of conveyance in carriages or omnibuses over a very rough kind of paving. The city is built, like the towns and cities of the United States, in square blocks, the streets being straight, parallel, and at right angles. Almost every street has its line of tramway, laid for the most part on Livesey's system, afterwards described. The principal lines are known as the City, the Billinghurst (now the Argentine), the Lacroze, the National, the Mendez, and the Southern Tramways. One particular feature which added to the cost of working these tramways was the necessity, some years ago, for having "trumpeters"—men on horseback who ride in advance of the cars each blowing a trumpet—to warn off carts and other vehicles from the track, as well as to prevent collisions at the intersections of the streets, and, further, to assist in dragging out of the way any heavily laden or broken-down vehicle obstructing the line.*

The modern tramway was introduced in England by Mr. G. F. Train, who, in 1857, made proposals for laying tramways on the system originated in Philadelphia in some of the Metropolitan thoroughfares and in a few provincial towns. Mr. Train associated with himself Mr. James Samuel, C.E., but they failed in their object of obtaining an Act of Parliament, which was applied for in 1858, mainly through the opposition of Sir Benjamin Hall, Chief Commissioner of Works. "It was utterly impossible," he said, "that the iron rails or plates upon which the carriages were to run could be laid on macadamised roads, for instance, with a certainty of always being kept on precisely the same level as the road; and carriages running diagonally against the plate would be subjected to have their wheels torn off, and most serious accidents would result whatever precautions might be taken. Even the weather would at times effect this."†

"Sir Benjamin Hall," said Mr. Train, "did not meet the arguments of Mr. Samuel except by prejudice. Arguing against facts is difficult, and over-riding stubborn truths impossible." Sir Benjamin, nevertheless, was proved to be in the right.

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* *Engineering*, May 17, 1872, page 332.

† *Observer*, February 21, 1858.

In default of better authority, Mr. Train, in March, 1860, applied for, and in May of the same year obtained, permission from the Commissioners of Birkenhead to lay down his tramway in this town. In April he patented his system.

"The egg," Mr. Train said, "will shortly be chipped in this country under my patent, at great cost and labour, and I shall endeavour to prevent my chicken (as is too frequently the case with valuable inventions) from becoming somebody else's hen."

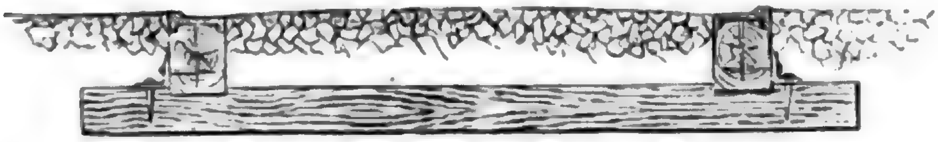

FIG. 15. Mr. G. F. Train's tramway at Birkenhead. Scale $\frac{1}{24}$.

So, the first of his lines was laid in the macadamised roads of Birkenhead, and was opened on August 30, 1860, within five months after the application for leave was made. It is illustrated by Figs. 15 and 16. It has rolled wrought-iron step-rails, weighing about 50 lbs. per yard, laid to a gauge of 4 feet 8½ inches. The rails were 6 inches wide and $\frac{9}{16}$ths of an inch thick in the sole, with a step rising ¾ inch above the sole, and a fillet at each edge on the lower side. They were bedded on and spiked to longitudinal timber sleepers, 6 inches wide and 8 inches deep, which were let into and rested on transverse sleepers, and were spiked to them with one iron knee to each.

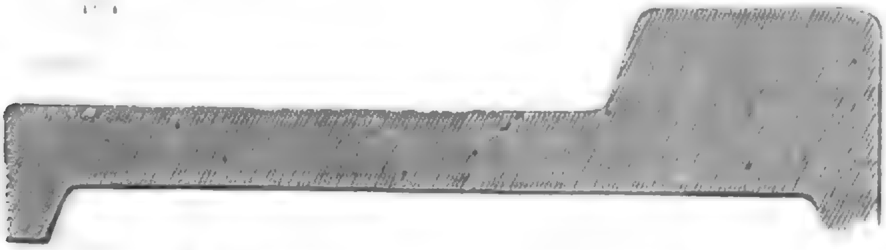

FIG. 16. Mr. G. F. Train's tramway at Birkenhead: Section of rail. Scale ½.

Short lines, similarly, were, by the permission of the local authorities, laid down in London by Mr. Train and his friends in 1861; in Bayswater Road, between the Marble Arch and Notting Hill Gate; in Westminster, from the Palace Hotel to Victoria Station; and in Kennington Road, from Westminster Bridge to Kennington Park. In 1863 a line 1¾ miles in length was laid by Mr. Train and opened in the Potteries District for the Staffordshire Potteries Street Railway Company, between Burslem and Hanley.

After a brief experience of the inconvenience of the step-rail, Mr. Train's lines laid in London were removed, whilst the Birkenhead Tramway and the Potteries Tramway were only saved from extinction by the timely substitution of flat grooved rails for the step-rails. The grooves in the new rails were sufficiently roomy to afford free play for the flanges of the wheels, at the same time that they were sufficiently narrow to prevent the wheels of common road vehicles from entering them.

Our streets and roads being in comparatively good condition, with cabs and omnibuses in common use, great numbers of which were available for general circulation at reasonable fares, the need for tramway accommodation was less urgent in England than elsewhere. The advocates of tramways, discouraged by the sensational failures, retired for a time. Mr. Beresford Hope said, "I have often been button-holed in society about it, and I should say that the general population of London look upon the extension of tramways with dislike and apprehension."

In fine, the career of the step-rail tramway was ended. However it may have been tolerated in America, it was hated in England; and only after an interval of some years—in 1865 and 1866—was the movement for the construction of tramways revived.

It may be noted that, obviating the vice of the step-rail, flat rails were laid in Salford, on Mr. John Haworth's system, about the year 1862, consisting of two parallel lines of smooth iron plates, 4½ inches wide and ½ inch thick, and a central grooved rail, similar in section to an inverted bridge rail. These rails were laid upon and screwed down to longitudinal timber sleepers, and finished flush with the surface of the pavement. Whilst the wheels of the vehicle rolled freely over the tram-plates a small guide-wheel, having a central flange, ran upon the central rail. The guide-wheel was hung from the front of the ordinary omnibus, and was raised or depressed at will by the driver. This triple-rail system, known as the "on-and-off" system, was in operation for upwards of eight years; but it was too weak, insomuch as it worked loose at the joints, and the ends occasionally opened up, making dangerous footing for the horses. Besides, it was open to the objection of slipperiness, and eventually the episodical tramway was removed.

CHAPTER II.

MODERN TRAMWAYS IN THE UNITED KINGDOM.

In November, 1865, a show piece of tramway, six yards in length, was laid in Castle Street, Liverpool, with the crescent rail, 3 inches wide, weighing 18 lbs. per yard, imported from America, laid as in Fig. 17, on which great expectations were based. The crescent rail, which was certainly flat enough and unassuming enough, had been employed in the construction of tramways in the United States, and, as it lay perfectly level with the pavement of the street, it was hailed by its admirers as a satisfactory solution of the problem of a non-obstructive street railway. The rails were laid and screwed down to longitudinal bearers, which rested on cross-sleepers. A small groove, or slot opening, was left in the

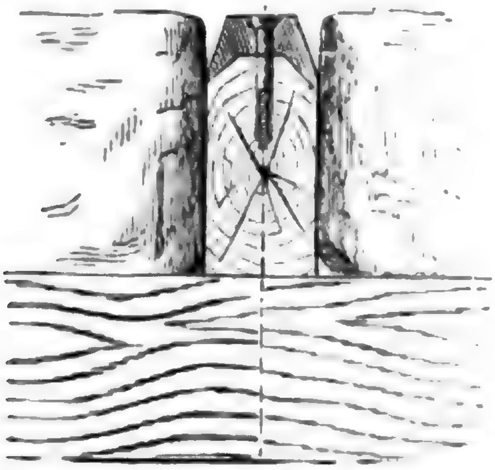

Fig. 17. Crescent rail, by Mr. J. Noble. Scale $\frac{1}{8}$.

pavement to clear the flanges of the wheels. The provision thus made for clearing wheel flanges was insufficient, and it was necessary in practice to employ special appliances for sweeping the groove clear of obstructive matter, whilst the tractional resistance must have frequently been excessive. Besides, the unprotected edges of the paving were liable to breakage. The system was finally abandoned, though it formed part of the original scheme of the Liverpool tramways; and the sample line did good service in allaying the apprehensions of the timid, and in silencing the objections of the fastidious. The sample piece was removed after it had laid four years in Castle Street.

The type of rail finally adopted for the first Liverpool tramways was formed with a flat level surface, having a narrow groove to receive and guide the wheel flanges.

In 1866 and 1867 application was made to Parliament for power to construct a system of tramways in Liverpool, for which an Act was obtained in 1868. This was the first English system of tramways for passenger traffic that was authorised by Act of Parliament. The works were constructed by Messrs. Fisher and Parrish, of New York, under Mr. George Hopkins as engineer-in-chief, and were commenced in May, 1869. The south line, from the Exchange to Dingle, 3 miles 560 yards in length, was opened on November 1, 1869. The north line, from Old Haymarket to Spillow Lane and Whitechapel Street, 2 miles 700 yards long, was opened on September 1, 1870; and the line on Aigburth Road, which has since been removed, 1 mile 260 yards long, was opened a year later, on September 1, 1871. Thus the total authorised length of tramway, or of streets traversed by tramways, amounted to 6 miles 1,520 yards, and it was constructed in the course of about two years and three months. The length constructed was about 5¾ miles in length, thus:—

	Miles.	Yards.
Single line	2	820
Double line	3	630
Total	5	1,450

The system was like a Catherine wheel: it consisted of an inner circle a mile and quarter long, from which two lines flew off. The inner circle is always worked in one direction, and then the carriages shoot off to the north. There are now (1891) about 28¼ miles of tramway in Liverpool.

The gauge of the Liverpool tramways was determined to be 4 feet 8½ inches—the same as the national railway gauge. But it was not fixed at that width with any view to a possible communication with railways. As a matter of fact railway wagons cannot be run over the ordinary groove rails of tramways laid to the railway gauge. The gauge of 4 feet 8½ inches was introduced in the Act because, when the promoters first applied to Parliament, they were obliged to apply as for a "railway," since the word "tramway" was not to be found in the standing orders, and they were under the necessity of accepting the only gauge allowed for railways.

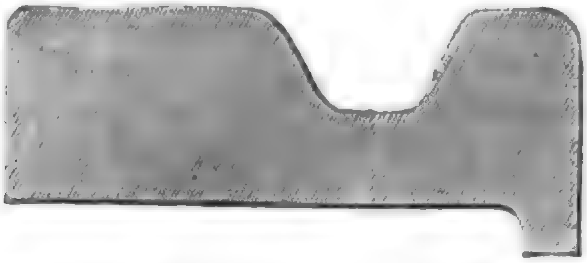

FIG. 18. Early Liverpool rail. Scale ½.

The form of the rails adopted in the original construction of the Liverpool tramways was, as before stated, of a flat grooved section, such as had been found to answer satisfactorily at Birkenhead, though narrower, weighing 40 lbs. per yard, about 1 inch in thickness and having a sectional area of about 4 square inches. Rails of similar but larger section were afterwards employed, weighing 45 lbs. per yard, shown in Fig. 18. The rail was little else than a flat bar, having a narrow and shallow groove in its upper surface, with a fillet on the lower side and bedded on a longitudinal sleeper. The rail was 4 inches wide and 1⅜ inches in thickness. The groove was formed with sloping sides, and was ¾ inch in depth, with a width of

⅝ inch at the bottom and double this width at the surface of the rail. The tread, or rolling surface for the wheels, had a width of about 2 inches, when of course, the inner edge of the tread was at the half-width of the rail; whilst the ledge forming the other side of the groove was about ⅞ inch wide at the surface, and was corrugated transversely with a view to preventing slipperiness for horses. The rails were bedded on timber sleepers 4 inches wide and 6 inches in depth, and were fished with ⅞-inch wrought-iron plates, 12 inches long and 4 inches wide, applied below the joint, let flush into the upper side of the sleeper as shown in Fig. 20. The joint was fixed with four vertical spikes, two to each rail, driven through the rails at the bottom of the groove, and the fish-plate, into the sleeper. The rails were also spiked at intervals to the sleepers. The heads of the spikes were countersunk, and let into the rails to finish flush with the bottom of the groove. The combined sleeper and rail thus presented, for the most part, a vertical surface at each side, against which paving stones could be closely and evenly jointed. The construction of the way is shown in cross section by Fig. 19. To render the way independent for support, on uncertain or unbroken ground, the roadway was excavated to a depth of 14½ inches for the whole width, and a

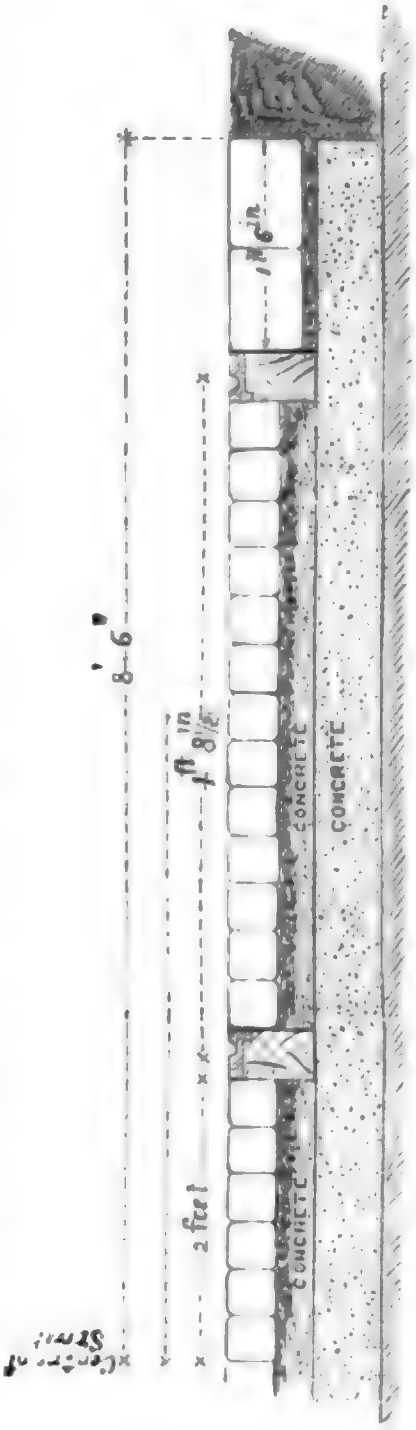

FIG. 19. First Liverpool Tramway. Half-width section. Scale 1/24.

continuous bed of lime concrete, 7 inches thick, was laid for the whole width of the track, as a foundation, upon which the sleepers were placed. The interspaces between the sleepers were filled up with concrete to the right level for supporting 4 inch cubes. The sleepers were laid in and spiked to cast-iron clip-chairs (Figs. 20, 21), which were placed about 4 feet apart longitudinally and rested direct on a concrete foundation. The gauge of the rails was fixed by bar-iron cross-ties, 1½ inches deep by ⅜ inch thick, the ends of which were dovetailed into grooves cast in the inner side of the chairs. The chairs were 6 wide inches at the joints of the sleepers, and 3 inches intermediately. The roadway was nearly all of macadam, and the materials for the concrete were taken from the macadam

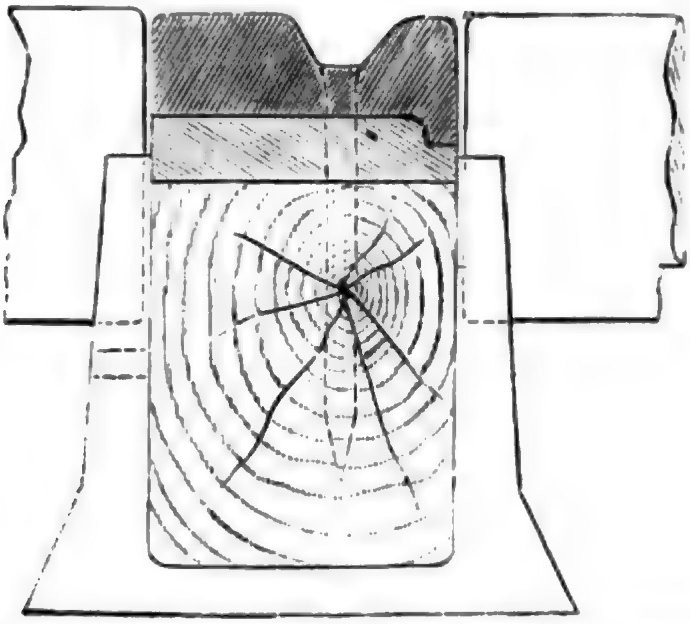

FIG. 20. First Liverpool tramway. Section of rail and sleeper, showing cast-iron chair and fish-joint. Scale ¼.

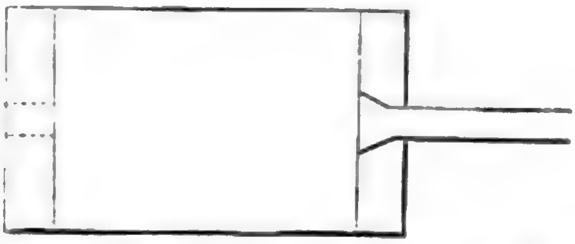

FIG. 21. First Liverpool tramway:—Cast-iron chair for longitudinal sleepers, and cross tie-bar. Scale ¼.

which was lifted to make room for the lime, riddled, cleaned, and mixed with blue lias lime; whilst the whole of the surface between the rails, and for a width of 18 inches beyond the outer sides of the rails, was paved with Welsh granite sets: 4-inch cubes between the rails, and sets of 6 inches in depth for the outer 18-inch spaces. The outer width, 18 inches, was provided in the Act, and it defined the marginal boundaries of the breadth of roadway to be maintained by the tramway company. That width was, and is now accepted as a fair compromise; and, says Mr. J. Morris, "it does fairly represent the extent of possible injury even which the tramway can do to the road, and it is accepted universally on the Continent, and almost universally in America, and is the recognised standard." *

The 18-inch margin is both necessary and sufficient for maintaining the stability of the line, when it is laid in a non-paved or macadamised street, and for affording a foothold for the tram-horses when they traverse the rails. "I remember," says Mr. Hopkins, "that our first bills were introduced with 9 inches only outside the rails, but the width was increased to 18 inches in Committee." †

Where the lines of tramway were double, in Liverpool, they were laid at a clear distance apart of four feet between the rails, giving a "four-foot," corresponding to the "six-foot" of railways.

The gradients of the Liverpool lines of tramway are various. Liverpool is a very hilly town. The maximum gradient is 1 in 19.

The practice initiated at Liverpool has ruled the general dispositions of tramways in other parts of the country.

In 1869, the North Metropolitan Tramways Company was authorised to lay tramways on the Whitechapel, Mile End, and Bow Roads; and in 1870 they were empowered to lay extensions to Aldgate, at the West-end, and to Stratford, Leytonstone, and Bromley, at the East-end. In 1871, they obtained additional

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* Report of the Select Committee on Tramways Bill, 1870.

† *Ibid.*

powers to lay tramways in the North and East of London, which made a total of 30¼ miles of tramway authorised to that Company. Now, in 1891, there is a length of 41¾ miles of way.

In 1869, also, Acts were passed for the construction of the Kennington, Brixton, and Clapham routes, from Westminster Road, by the Metropolitan Street Tramway Company; and the routes from Pimlico, by Vauxhall, to Greenwich, by the Pimlico, Peckham, and Greenwich Tramway Company. These two Companies were, by their Acts, empowered to construct and work tramways in nearly all the main metropolitan thoroughfares on the south side of the Thames, comprising 25 miles of streets. They were amalgamated, in the end of 1870, as the London Tramways Company. In 1891, 21¾ miles of way were open.

In 1870, the London Street Tramways Company were authorised to lay tramways on the north side of London, from Lower Holloway to the south end of the Hampstead Road, and from Kentish Town to King's Cross. In 1891, 13½ miles of way were open.

In the beginning of 1873, 42 miles of tramway had been opened in the streets of the Metropolis; the length was increased to 61 miles in 1876, and to 130 miles in 1891.

PART II.
STATISTICS OF TRAMWAYS.

CHAPTER I.

GENERAL STATISTICS.

UNDER the stimulus afforded by the rapid spread and successful operation of the several systems at work, Acts were applied for and obtained, authorising the laying of tramways in many cities and towns in the provinces :—

Year.	No. of Tramway Acts passed.	Year.	No. of Tramway Acts passed.
1868	1	1881	32
1869	3	1882	43
1870	11	1883	25
1871	11	1884	30
1872	13	1885	21
1873	22	1886	19
1874	8	1887	19
1875	14	1888	20
1876	9	1889	18
1877	22	1890	2
1878	26		
1879	31	23 years.	Total 439
1880	39		

These columns show a period of increasing activity in tramway legislation, culminating in 1880—82, followed by a period of decreasing activity. In 1890, only two Acts were passed.

The total lengths of streets and roads traversed by tramways in the United Kingdom, at June 30. 1890, were as follows :—

Kingdom.	Length of tramway open		
	Double line.	Single line.	Total.
	Miles.	Miles.	Miles.
England and Wales	314·40	438·15	752·55
Scotland	62·81	21·59	84·40
Ireland	38·00	73·31	111·31
Totals	415·21	533·05	948·26

The capital expenditure on tramways at June 30, 1890, amounted to about 13¾ millions sterling, distributed as follows:—

June 30, 1890.	Capital expenditure on lines and works open for traffic.	Total expenditure on capital account.	Length open for traffic.			Number of undertakings.
			Double.	Single.	Total.	
	£	£	Miles.	Miles.	Miles.	
Tramways belonging to Local Authorities	2,152,392	2,911,419	146·00	97·75	243·75	29
Tramways belonging to others	8,215,125	10,824,350	269·21	435·30	704·51	129
Total, United Kingdom	10,367,517	13,735,769	415·21	533·05	948·20	158

The capital expended on lines and works open for traffic is at the rate of about £10,580 per mile. The total expenditure on capital account is as follows for the three kingdoms separately:—

June 30, 1890.	Total capital expenditure.	Expenditure per mile open.
	£	£
England and Wales	11,136,027	14,800
Scotland	1,366,938	16,200
Ireland	1,232,804	11,100
United Kingdom	13,735,769	14,500

Showing an average total expenditure of £14,500 per mile of tramways open. The greater cost per mile for Scotland arises from the greater proportion of double line to single line than in the other countries; and the less cost per mile for Ireland arises from the less proportion of double line.

The working stock at June 30, 1890, was as follows:—

27,719 horses, or	*per mile open*	29·27
575 locomotives	,,	·61
28,294 horses and locomotives .	,,	29·88
3,801 cars	,,	4·01
Horses and locomotives . . .	*per car*	7·44

The number of miles run by cars during the year ending June 30, 1890, amounted to 65,174,955 miles; and, taking the mean number of cars for the year at 3,723, the mileage run per car averages 17,506 car-miles for the year, or 48 miles per car per day, allowing 365 working days in the year; against 44 in the year 1879—80.

Taking, again, the average number of horses for the year, at 27,390 horses, or 13,695 pairs; and of locomotives at 557; these give together 14,252 pairs of horses and locomotives, running 4,573 miles in the year, per pair of horses and per engine, or 12·5 miles per day, against 11 miles in the year 1879—80. A slight abatement in the average is due on account of one-horse cars employed.

The gross receipts for the year ending June 30, 1890, amounted to £3,214,743, and the expenses to £2,402,800, or 75 per cent., leaving the net receipts £811,943. Taking the capital expenditure for the year on lines and works open at £10,327,517, the proportions of earnings and expenses are as follows. The proportions for the year to June 30, 1880, are added for comparison:—

	Year to June 30, 1890.	Year to June 30, 1880.
Gross receipts	31·1 per cent. of capital expenditure	26·9 per cent.
Expenses .	23·3 ,, ,, ,,	22·3 ,,
Net receipts .	7·8 ,, ,, ,,	4·6 ,,

In Table No. 1, annexed, are given in summary the capital cost, receipts, expenses, and working stock of tramways in the United Kingdom for the years ending June 30, 1878, 1882, 1884, 1886, 1888, 1889, and 1890.

In Table 2 are given, for each tramway, the capital expenditure, and the lengths authorised and open at June 30, 1890.

In Table 3 are given the receipts, working expenditure, and stock of horses, locomotives, and cars for each tramway, at June 30, 1890, with number of passengers, and car-miles run.

The contents of these three tables are derived from the *Tramways Return*, 1890.

In Table 4 is given the working expenditure on the whole of the tramways of the United Kingdom, for the year ending June 30, 1890, abstracted from Table 3, with the percentage proportions in parts of the total expenditure. The corresponding expenditure for the year ending June 30, 1880, are added for comparison.

TABLE NO. 1.—CAPITAL COSTS, RECEIPTS, EXPENSES, AND WORKING STOCK OF TRAMWAYS IN THE UNITED KINGDOM FOR THE YEARS ENDING 30TH JUNE, 1878, 1882, 1884, 1886, 1888, 1889, 1890.*

For years ended 30th June.		Length of lines open for public traffic.	Number of horses belonging to the companies.	Number of locomotive engines belonging to the companies.	Number of cars belonging to the companies.	Total number of passengers carried.	Total capital expended.	Gross receipts.	Working expenses.	Net receipts.
		Miles.	Horses.	Engines.	Cars.	Passengers.	£	£	£	£
ENGLAND & WALES	1878	194	6,269	6	802	80,442,108	3,121,268	791,677	579,471	166,012
	1882	444	13,741	62	1,794	187,875,779	6,304,539	1,516,845	1,225,906	290,939
	1884	612	17,102	186	2,426	252,612,893	8,933,925	1,919,197	1,486,098	433,099
	1886	706	19,388	422	2,772	302,790,839	10,345,879	2,110,918	1,639,390	471,528
	1888	736	19,976	479	2,815	340,511,905	11,315,740	2,248,117	1,755,345	492,772
	1889	758	21,369	496	2,923	379,580,965	11,171,451	2,375,032	1,831,846	543,186
	1890	753	21,681	534	3,030	418,399,936	11,136,027	2,573,535	1,932,444	641,091
SCOTLAND	1878	43	2,122	8	210	47,680,256	657,943	253,011	212,960	40,051
	1882	64	3,062	10	343	56,137,402	1,038,852	314,205	216,902	97,303
	1884	70	3,314	11	373	61,324,499	1,101,614	339,249	241,719	97,530
	1886	73	3,499	17	384	59,528,415	1,157,559	335,900	243,693	92,207
	1888	79	4,223	19	392	63,744,042	1,246,593	359,933	276,586	82,717
	1889	81	3,908	21	399	70,583,156	1,287,125	366,971	277,746	119,225
	1890	84	4,126	19	423	76,008,545	1,366,938	417,350	296,463	120,857
IRELAND	1878	32	831	—	112	8,878,859	428,139	100,777	75,884	24,893
	1882	56	1,327	4	215	13,746,879	918,424	139,300	112,985	26,315
	1884	70	1,368	10	239	16,857,013	951,013	162,309	124,222	38,087
	1886	86	1,648	13	284	21,838,270	1,069,603	183,520	138,473	37,047
	1888	89	1,633	16	294	24,740,098	1,173,352	188,849	143,503	45,316
	1889	110	1,783	22	323	27,432,147	1,206,015	208,221	157,089	51,132
	1890	111	1,912	22	348	31,960,837	1,232,804	223,858	173,893	49,995
TOTAL FOR UNITED KINGDOM	1878	269	9,222	14	1,124	146,001,223	4,207,350	1,145,465	868,315	230,956
	1882	564	18,130	76	2,352	257,760,060	8,261,815	1,970,350	1,555,793	414,557
	1884	752	21,784	207	3,038	330,794,405	10,989,552	2,420,755	1,852,039	568,716
	1886	865	24,535	452	3,440	384,157,524	12,573,041	2,630,338	2,021,556	600,782
	1888	904	25,832	514	3,501	428,996,045	13,735,685	2,796,899	2,175,434	620,805
	1889	949	27,060	539	3,645	477,596,268	13,664,591	2,950,224	2,266,681	713,543
	1890	948	27,719	575	3,801	526,369,328	13,735,769	3,214,743	2,402,800	811,943

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* Similar particulars for the years ending 30th June, 1891, 1892, 1893, will be found in Appendix B (p. 728).

TABLE NO. 2.—CAPITAL EXPENDITURE, AND LENGTHS OF TRAMWAYS AUTHORISED AND OPEN IN THE UNITED KINGDOM, AT JUNE 30, 1890.

ENGLAND AND WALES.

Years in which acts were passed.	Name of tramway, and gauge. * Mechanical power authorised (subject in most cases to Board of Trade approval).	Capital expended.								Authorised length.			Length open.		
		On lines and works open.	On lines and works in course of construction	On horses.	On locomotive engines.	On cars.	Legal and Parliamentary.	Sundries.	Total.	Double line.	Single line.	Total.	Double line.	Single line.	Total.
		£	£	£	£	£	£	£	£	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.
1882—1883	Accrington Corporation*	33,500	...	...	...	...	1,800	...	35,300	1 32	4 46	5 78	1 25	4 6	5 31
	4 ft.	34,181	...	...	11,200	3,232	365	3,774	52,755	0 57	3 28	4 5	0 57	3 28	4 5
1880—1883	Alford and Sutton*	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2 ft. 6 in.														
1884—1880	Barrow-in-Furness*	51,326	...	...	5,214	2,026	1,651	4,724	64,941	1 45	5 17	6 62	0 70	3 21	4 11
	4 ft.														
1877—1878	Barton, Eccles, Winton, & Monton Local Board	17,000	...	...	...	...	.	..	17,000	...	2 10	2 10	...	2 10	2 10
	4 ft. 8½ ins.														
1880—1881	Bath	7,700	...	325	...	589	80	116	8,810	0 41	1 16	1 57	0 41	1 16	1 57
	4 ft.														
1880—1883	Birkdale and Southport*	16,315	.	467	...	912	...	161	17,855	0 73	4 33	5 26	0 29	2 20	2 49
	4 ft. 8½ ins.														
1872—1880	Birkenhead	...	...	...	...	...	...	...	...	5 79	3 5	9 4	5 21	2 65	8 6
	4 ft. 8½ ins.														
1880—1885	Birmingham and Aston*	40,647	...	450	15,551	3,429	6,074	2,608	68,762	1 14	2 52	3 66	1 14	2 52	3 66
	3 ft. 6 ins.														
1881—1880	Birmingham & Midland*	125,498	...	...	19,588	5,250	9,105	2,495	161,936	2 4	6 76	9 0	2 4	6 76	9 0
	3 ft. 6 ins.														
1880—1888	Birmingham Central*	320,832	.	26,206	58,993	45,220	132466	13,843	597,560	5 70	9 29	15 10	3 9	5 5	8 14
	3 ft. 6 ins.														
1872—1886	BirminghmCorporation*	171,512	...	...	..	...	749	.	172,261	14 70	7 28	22 18	13 51	5 75	19 46
	3 ft. 6 ins.														
1879—1880	Blackburn and Over Darwen*	30,618	...	...	6,833	3,006	5,502	1,994	47,953	0 40	4 55	5 15	0 40	4 55	5 15
	4 ft.														
1882—1889	Blackburn Corporation*	66,511	1,236	2,940	14,000	5,510	1,794	12,813	104,804	1 35	10 49	12 4	1 29	7 4	8 33
	4 ft.														

834—188	Blackpool Corporation* 4 ft. 8½ ins.	12,833 11,570	...	... ...	... 3,187	... 1,785	582 1,591	... 2,541	13,435 20,694	0 49	1 30	1 79	0 49	1 30	1 79
					(fixed generators, &c.										
878—188	Bolton and Suburban* 4 ft. 8½ ins.	58,024 8,839 7,314 1,406	... ...	... ...	... ...	... ...	1,650 239 503 503	2,153	61,836 9,078 7,817 1,009	4 41 0 27 0 67 0 9	5 45 1 13 1 19 0 10	10 6 1 40 2 6 0 25	4 41 0 27 0 62 0 9	5 45 1 13 0 10 0 16	12 03
881—188	Bootle Corporation* 4 ft. 8½ ins	37,249	...	...	...	...	380	...	37,629	2 65	1 29	4 14	2 51	0 40	3 20
885—188	Bradford and Shelf* 4 ft.	8,000 3,164	... ...	... ...	... ...	... ...	... ...	... ...	8,000 3,164	2 1 0 5	... 0 52	2 1 0 57	2 1 0 5	... 0 52	2 1 0 57
880—188	Bradford Corporation* 4 ft.	71,695 14,786 4,072	400	... 1,800 ...	... 17,988 10,320	... 7,830 3,087	2,433 550 ...	... 463 1,151	74,528 41,417 10,230	5 45	6 51	12 27	5 54	6 53	12 27
885—1888	Brentford and District 4 ft. 8½ ins.	...	...	...	...	...	2,216	...	2,216	1 18	5 6	6 24	...	...	
882—188	Brighton & Shoreham* (formerly Brighton Dist.) 3 ft. 6 ins.	6,770	...	900	100	1,030	...	...	8,890	0 65	3 72	4 57	0 61	3 61	4 42
874—188	Bristol* 4 ft. 8½ ins.	124,110	...	12,600		13,845	11,116	9,924	171,895	4 65	6 50	11 35	4 62	6 20	11 2
1879—188	Burnley and District* 4 ft. 8½ ins.	58,013	27	...	9,745	3,045	373	...	71,203	1 62	0 73	[illegible] 55	1 19	5 73	7 12
381—188	Bury, Rochdale, and Oldham 3 ft. 6 ins. & 4 ft. 8½ ins.	106,004	...	...	22,900	Included in previous column.	13,214	1,029	143,147	8 64	27 21	36 6	6 38	23 64	30 22
1879—1881	Cambridge Street 4 ft.	25,000	...	Details of capital expenditure not given.					25,000	0 54	2 0	2 54	0 54	2 0	2 54
1871—188	Cardiff 4 ft. 8½ ins.	135,931	...	Details cannot be supplied.					135,931	2 48	4 46	7 14	2 48	4 46	7 14
1880—188	Cardiff District and Penarth Harbour* 4 ft. 8½ ins.	15,650	...				688	5,340	21,678	0 33	2 6	2 39	0 31	2 2	2 33
1880—189	Chesham, Boxmoor, and Hemel Hempsted* 4 ft. 8½ ins.	...	...			...		...	...	0 13	8 14	8 27	...		
1878—187	Chester 4 ft. 8½ ins.	31,470		2,174		2,086	...	200	36,320	0 79	1 31	2 30	0 79	1 31	2 30
1880—1881	Chesterfield 4 ft. 8½ ins.	830	...	130	...	406	43	36	1,445	0 18	1 0	1 8	0 18	1 0	1 18
180—188	Coventry and District* 3 ft. 6 ins.	94,993	...		Details not given.			...	94,993	1 14	4 46	5 60	1 14	4 46	5 60
1878—1890	Croydon (formerly Croydon and Norwood)* 4 ft. 8½ ins.	68,000	...	...	...	...		...	68,000	1 30	9 33	10 63	1 30	5 33	6 63

TABLE No. 2.—ENGLAND AND WALES (*continued*).

Years in which Acts were passed.	Name of tramway, and gauge. * Mechanical power authorised (subject in most cases to Board of Trade approval).	Capital expended.								Authorised length.			Length open.		
		On lines and works open.	On lines and works in course of construction.	On horses.	On locomotive engines.	On cars.	Legal and Parliamentary.	Sundry.	Total.	Double line.	Single line.	Total.	Double line.	Single line.	Total.
		£	£	£	£	£	£	£	£	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.
1879–188	Derby 4 ft.	54,049	Details of capital expenditure not given.						54,049	1 27	3 37	4 64	1 27	3 37	4 64
1873–188	Dewsbury, Batley, and Birstall* 4 ft. 8½ ins.	37,405	...	25	6,200	2,080	2,281	...	48,591	0 50	3 58	4 28	0 37	3 66	4 23
1880–188	Drypool and Marfleet* 4 ft. 8 ins.	7,315	...	...	5,228	1,059	1,286	125	15,013	0 18	1 12	1 30	0 17	1 10	1 27
1885–188	Dudley & Kingswinford* 3 ft. 6 ins.	..				..	1,821	504	2,325	0 52	2 25	2 77	...	..	...
1881–188	Dudley and Stourbridge* 3 ft. 6 ins.	35,917	...	..	6,344	1,034	4,000	335	50,130	0 44	4 48	5 12	0 44	4 48	5 12
1880–1885	Dudley, Sedgley, and Wolverhampton* 4 ft. 8½ ins.	...		...		...	...	...	...	0 36	5 26	5 62	0 36	5 26	5 62
1881–188	Exeter 3 ft. 6 ins.	2,575	...	...	...	...	...	...	2,575	0 26	2 4	2 30	0 26	2 4	2 30
1887–188	Flamborough Head* 3 ft. 6 ins.	...	...	..	...	...	813	...	813	0 26	3 12	3 38	...	...	...
1884–18	Folkestone, Sandgate, and Hythe* 4 ft. 8½ in.	...	7,293		...	...	6,543 (including deposit)	132	13,968	0 12	3 65	3 77	...	...	...
1880–188	Gateshead and District* 4 ft. 8½ ins.	[illegible]			12,000	4,315	15,660	1,080	[illegible]	1 55	4 65	6 40	1 55	4 65	6 40
1878–18	Gloucester 4 ft.	16,000	Undertaking purchased for a lump sum						15,000	0 41	2 36	2 77	0 41	2 36	2 77
1882–188	Gosport, Alverstoke, and Bury Cross* 3 ft.	...	...	...	...	...	...	...	...	0 29	2 6	2 35	...	...	...
1881–188	Gravesend, Rosherville and Northfleet* 3 ft. 6 ins.	11,084	...	...	..	836	3,975	4,136	20,031	0 17	2 3	2 20	0 17	2 3	2 20

1879—188	Great Grimsby 4 ft. 8½ ins.	30,327	...	2,535	...	2,030	2,158	...	37,050	1 12	3 66	4 78	1 4	3 63	4 67
1886—188	Harrow Rd & Paddington 4 ft. 8½ ins.	55,210	...	3,850	...	3,060	5,414	6,843	74,377	1 60	0 1	1 61	1 60	0 1	1 61
1883—188	Hartlepools* . 3 ft. 6 ins.	20,500	...	...		...	7,000	...	36,500	0 50	1 65	2 41	0 50	1 65	2 41
882—188	Highgate Hill* 3 ft. 6 ins.	...	...	...	...	...	...	...	...	0 41	0 16	0 57	0 48	0 9	0 57
1880—188	Huddersfield Corprtion* 4 ft. 8½ ins.	62,352	3,391	...	13,85	4,880	1,801	8	86,453	1 70	16 41	18 31	0 70	10 23	11 19
1872—187	Hull Street 4 ft. 8½ ins.	95,877	...	4,440	...	7,322	182	...	107,821	1 51	9 14	10 65	1 51	9 14	10 65
879—188	Ipswich* . 3 ft. 6 ins.	31,030	...	614	...	1,300	283	70	33,297	0 68	3 33	4 21	0 68	3 33	4 21
1888—188	Keighley* 4 ft.	12,561	...	1,070	...	1,078	751	790	16,250	0 62	3 21	4 6	0 55	1 53	2 28
1889—189	Lancaster and District* 4 ft. 8½ ins.	...	19,646	665	...	103	730	1,774	22,918	—	5 69	5 69	...	...	...
1881—189	Lea Bridge, Leyton, and Walthamstow* 4 ft. 8½ ins.	7,150	...	...		...		...	7,150		3 38	3 38	...	2 32	2 32
1879—188	Leamington & Warwick 4 ft. 8½ ins.	18,666	...	1,229	...	64	1,643	401	22,045	0 23	2 57	3 0	0 23	2 57	3 0
1871—1882	Leeds (Company)* . 4 ft. 8½ ins.	142,600	...	9,870	15,757	14,230	2,282	2,388	187,127	6 5	8 28	14 33	6 5	8 28	14 33
1889—188	Leeds Corporation* 4 ft. 8½ ins.	—	15,232	...	...	...	...	...	15,232	2 25	1 48	3 73	...	...	...
1873—1885	Leicester 4 ft. 8½ ins.	97,707	...	10,201	...	12,003	5,504	...	125,275	2 37	9 0	11 37	1 73	7 1	8 74
1881—1882	Lincoln 3 ft. 6 ins.	8,025	...	208		800	1,170		10,203	0 22	1 42	1 64	0 22	1 42	1 64
1881—189	Lincolnshire* . 3 ft. 6 ins.	...	18,565	...		...	...	...	18,565	0 54	23 20	23 74	...	...	...
1868—188	Liverpool Corporation* 4 ft. 8½ ins.	298,557	...	...	...	...	5,012	...	303,569	18 1	10 26	28 27	18 1	10 26	28 27
		182,102	...	70,986	—	Cars. 35,004 buses 8,070	10,459	245,015	501,689						
1880—1881	Llanelly 3 ft.	7,260	...	79	...	684	...	696	8,719	0 21	1 29	1 50	0 15	0 60	0 75
1869—189	London* . 4 ft. 8½ ins.	444,207	...	108,174	...	47,060	...	15,681	615,022	21 73	1 27	23 20	20 31	1 27	21 58
1882—1888	London, Camberwell, & Dulwich 4 ft. 8½ ins.	...	24,150	...		...	6,000	...	30,150	0 30	2 70	3 20	3 20	...	...
1882—188	London Southern . 4 ft. 8½ ins.	111,560	...	Details	cannot	be	given.		111,560	1 73	3 67	5 60	1 73	3 67	5 60

TABLE No. 2.—ENGLAND AND WALES (*continued*).

Years in which acts were passed.	Name of tramway, and gauge. * Mechanical power authorised (subject in most cases to Board of Trade approval.	Capital expended.								Authorised length.			Length open.		
		On lines and works open.	On lines and works in course of construction	On horses	On locomotive engines.	On cars.	Legal and Parliamentary.	Sundries.	Total	Double line.	Single line.	Total.	Double line.	Single line.	Total.
		£	£	£	£	£	£	£	£	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.
1870—1880	London Street 4 ft. 8½ ins.	[illegible]		[illegible]	...	25,3[illegible]	10,[illegible]		41[illegible],75[illegible]	10 63	6 24	17 7	8 56	4 64	13 40
1877—1883	Manchester Carriage & Tramways Company 4 ft. 8½ ins	201,97[illegible]	...	[illegible]	...	[illegible]	13,[illegible]21	...	[illegible],171	21 37	3 52	25 9	21 37	3 52	25 9
1875—1882	Manchester Corporation 4 ft. 8½ ins.	123,25[illegible]			.	.	3,2[illegible]	300	126,8[illegible]	17 63	12 17	30 0	18 61	9 45	28 26
1885—1886	Manchester, Middleton and District* 3 ft. 6 ins.	...	...		.	.	...	.	...	0 47	8 35	9 2	...	...	...
1873—1882	Middlesbrough & Stockton 4 ft. 8½ ins.	6,51[illegible]	...	48[illegible]	2,011	1,20[illegible]	40[illegible]	...	14,51[illegible]	0 24	2 37	2 61	0 24	2 37	2 61
1880—188[illegible]	Morecambe 4 ft. 8½ ins.	11,68[illegible]		585	...	...	1,22[illegible]	[illegible]	14,0[illegible]	0 46	1 64	2 30	0 44	1 64	2 28
1878—18[illegible]	Moss Side Local Board 4 ft. 8½ ins.	10,6[illegible]		...	...	...	[illegible]	...	11,[illegible]	0 65	0 65	1 50	0 65	0 65	1 50
1873—188[illegible]	Neath and District 4 ft. 8½ ins.	31,11[illegible]		1,317	...	1,51[illegible]	1,13[illegible]	2,27[illegible]	39,353	0 22	3 64	4 6	0 22	3 64	4 6
1877—188[illegible]	Newcastle-upon-Tyne Corporation* 4 ft. 8½ ins.	63,4[illegible] 10,[illegible]		... 11,570	...	... 8,4[illegible]	25[illegible] 3,[illegible]	[illegible] 1,8[illegible]	63,75[illegible] [illegible]	7 16	5 [illegible]	13 4	1 16	[illegible]	11 [illegible]
1880—188[illegible]	Newport and Parkhurst 3 ft.	...	...	...	..	...	...		...	0 13	0 80	1 13	...		
1873—187[illegible]	Newport (Mon.) 4 ft. 8½ ins.	8,11[illegible]	..	[illegible]	..	8[illegible]	1,81[illegible]	[illegible]	11,84[illegible]	0 14	1 40	1 54	0 17	1 1	1 18
1887—1888	Newport Pagnell & District* 3 ft. 6 ins.		14,[illegible]	...	[illegible]		5[illegible]5	[illegible]	3[illegible],13[illegible]	0 53	5 38	6 11			
1878—1879	Newton Heath Local Bd. 4 ft. 8½ ins.	14,6[illegible]					68[illegible]	...	15,35[illegible]	1 60	0 7	1 67	1 60	0 7	1 67
1880—1883	Northampton Street* 3 ft. 6 ins.	15,[illegible]	..	2,80[illegible]	21,50[illegible]	2,[illegible]	3,50[illegible]	4,700	50,0[illegible]	0 66	3 34	4 20	0 66	3 34	4 20

1879—1887	North London* . . 4 ft. 8½ ins.	147,917	...	40	21,500	7,237	3,324	3,243	183,261	2 50	7 39	10 9	2 48	7 25	9 73
1869—1890	North Metropolitan* . 4 ft. 8½ ins.	1,080,897	Included in prev.col.	124,589	...	60,550	64,633	...	1,330,651	39 77	5 20	45 17	36 77	4 61	41 58
1879—1886	North Shields & Tynemouth District* . . 3 ft.	2,500	...	...	...	...	...	...	2,500	0 56	1 70	2 46	0 56	1 70	2 46
1879—1887	North Staffordshire* . 4 ft.	102,805	...	280	33,991	4,606	2,247	3,241	147,170	2 29	18 32	20 61	0 74	6 6	7 0
1878—1885	Nottingham & District*. 4 ft. 8½ ins.	85,495	...	11,407	917	9,060	2,220	1,397	110,500	7 40	3 0	10 40	7 40	3 0	10 40
1889—1890	Oldham, Ashton-under-Lyne, & Hyde Dist.* . 4 ft. 8½ ins.	...	...	...	...	...	...	...	...	...	8 1	8 1	...	...	...
1878—1883	Oldham Borough Corp.* 4 ft. 8½ ins.	47,267	...	...	...	...	715	724	48,706	3 56	4 77	8 53	3 45	4 64	8 29
1879—1887	Oxford (City of) & Dist. 4 ft.	46,069	...	3,010	..	2,257	...	1,422	52,758	1 2	3 0	4 2	1 2	3 0	4 2
1882—1890	Plymouth. . . . 3 ft. 6 ins.	...	6,000	...	...	220	2,500	700	9,420	0 30	3 20	3 50	...	...	...
1870—1875	Plymouth, Stonehouse & Devonport . . . 4 ft. 8½ ins.	51,128	...	Details	cannot	be su	pplied		51,128	...	1 74	1 74	0 12	1 62	1 74
1882—1889	Pontypridd & Rhondda Valley . . . . 3 ft. 6 ins.	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1883—1888	Portsmouth (Borough of Kingston, Fratton, & Southsea . . . 4 ft. 9½ ins.	41,295	...	...	...	1,810	Not yet ascertained	2,480	45,585	0 57	2 53	3 30	0 57	2 53	3 30
1870—1884	Portsmouth Street . 4 ft. 8½ ins. & 3 ft. 6 ins	159,695	...	...	...	...	...	...	159,695	1 76	14 69	16 65	0 21	11 56	11 77
1878—188	Preston Corporation & Fulwood Local Board 3 ft. 6 ins.	26,576 2,105	... ...	... ...	... ...	... ...	... 13	... ...	26,576 2,118	0 40 ...	6 31 1 1	6 71 1 1	0 61 ...	5 79 1 1	} 7 61
1878—187	Reading . . . . 4 ft.	19,486	...	680	...	1,396	1,125	862	23,549	0 49	1 59	2 28	0 66	1 44	2 30
1882—18	Rossendale Valley* . 4 ft.	38,106	...	...	8,800	2,400	3,513	2,349	55,168	1 10	8 7	9 17	0 60	4 16	4 76
1879—1884	St. Helen's and District* 4 ft. 8½ ins.	19,673	...	...	5,600	1,360	...	106	26,739	...	13 0	13 0	...	8 0	8 0
1875—188	Salford Corporation* 4 ft. 8½ ins.	90,137 ...	... ...	... 21,335	... ...	... 6,000	... ...	... ...	90,137 37,435	} 9 59	5 14	14 73	9 14	4 12	13 26
1872—187	Sheffield Corporation . 4 ft. 8½ ins.	90,507 51,883	... ...	... 14,640	... ...	... 9,200	... 8,288	... ...	90,507 84,011	} 9 46	0 58	10 24	9 14	0 20	9 34

TABLE No. 2.—ENGLAND AND WALES (*continued*).

Years in which acts were passed.	Name of tramway, and gauge. * Mechanical power authorised (subject in most cases to Board of Trade approval).	Capital expended.								Authorised length.			Length open.		
		On lines and works open.	On lines and works in course of construction.	On horses.	On locomotive engines.	On Cars.	Legal and Parliamentary.	Sundries.	Total.	Double line.	Single line.	Total.	Double line.	Single line.	Total.
		£	£	£	£	£	£	£	£	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.
1881—1886	Shipley* 4 ft.	25,853	...	...	...	...	...	2,378	28,231	0 27	1 78	2 25	0 27	1 78	2 25
187[illegible]—188[illegible]	Southampton Street 4 ft. 8½ ins.	70,45[illegible]	...	1,[illegible]	...	4,[illegible]	...	...	75,9[illegible]	0 28	5 52	6 0	...	5 3	5 3
1880—1887	South-Eastern Met. 4 ft. 8½ ins.	...	...	...	...	...	...	...	...	0 40	1 48	2 37	...	...	...
1881—1882	South Gosforth* 4 ft. 8½ ins.	13,000	...	4,000	...	2,000	1,000	500	20,500	0 20	0 30	0 50	0 20	0 30	0 50
1879—1884	South London 4 ft. 8½ ins.	271,721	...	22,5[illegible]	...	13,860	14,41[illegible]	23,28[illegible]	345,44[illegible]	8 23	4 49	12 72	8 23	4 49	12 72
1872—1877	Southport 4 ft. 8½ ins.	37,330	...	3,410	...	4,240	2,650	1,18[illegible]	48,010	0 79	5 43	6 42	0 74	5 48	6 42
1881—1884	South Shields Corp.* 3 ft. 6 ins.	17,918 ...	... ...	... 1,1[illegible]	... ...	... 1,200	73[illegible] 10[illegible]	1,2[illegible] 8[illegible]	19,92[illegible] 3,41[illegible]	1 70	4 31	5 68	0 64	1 59	2 43
1870—1890	South Staffordshire (formerly S. Staffordshire & Bir'ham District).* 3 ft. 6 ins.	310,178	...	1,020	33,718	5,520	9,08[illegible]	12,0[illegible]	371,[illegible]	10 35	14 70	25 25	0 53	12 78	13 51
1879—1880	Southwark and Deptford 4 ft. 8½ ins.	111,785	...	11,164	...	7,191	7,065	...	137,205	2 60	5 22	8 2	1 9	3 63	4 72
1889—1890	Stockport & Hazel Grove 4 ft. 8½ ins.	11,400	...	1,170	...	1,186	4[illegible]	31[illegible]	14,515	0 41	3 20	3 61	0 34	2 42	2 76
1880—1890	Stockton-on-Tees and District.* 4 ft.	74,042	...	1,012	4,370	2,757	151	654	83,3[illegible]	1 8	6 23	7 31	1 2	5 21	6 23
1878—1883	Sunderland (Company)* 4 ft. 8½ ins.	60,968	...	2,585	...	5,635	4,0[illegible]	2,47[illegible]	75,711	3 23	1 22	4 45	2 64	1 12	3 76
1879—1880	Sunderland Corporation* 4 ft. 8½ ins.	17,450	...	...	...	...	...	...	17,450	1 25	1 45	2 70	0 79	1 28	2 27
1874—1883	Swansea* 4 ft. 8½ ins.	81,338	...	3,213	2,213	3,231	12,318	5,886	108,199	4 12	1 27	5 39	4 12	1 27	5 39

1878—1887	Wallasey 4 ft. 8½ ins.	20,335	...	1,829	...	2,218	3,211	68	27,661	0 61	4 67	5 48	0 33	2 73	3 26
1880—1881	Walton-on-the-Hill Local Board.* 4 ft. 8½ ins.	31,718	...	...	...	...	1,030	1,243	33,000	3 12	0 8	3 20	3 12	0 8	3 20
1874—1877	Wantage* 4 ft. 8½ ins.	8,580	...	100	1,010	803	706	330	11,610	0 5	2 33	2 38	0 5	2 33	2 38
1878—1879	Wavertree Local Board 4 ft. 8½ ins.	9,220	...	...	...	...	578	1,104	10,902	0 62	0 28	1 10	0 62	0 28	1 10
1878—1883	West Derby Local Board 4 ft. 8½ ins.	39,369	...	...	...	...	1,810	323	41,502	4 1	1 22	5 21	4 1	1 22	5 21
1883—1890	West Metropolitan* 4 ft. 8½ ins.	171,643	...	10,715	...	6,835	6,135	8,447	200,775	2 65	5 75	8 61	2 63	5 76	8 59
1885—1891	Weston-super-Mare Clevedon & Portishead.* 4 ft. 8½ ins.	...	22,759	...	...	...	3,002	3,402	30,383	0 15	14 7	14 22	...	...	...
1879—1885	Wigan* 3 ft. 6 ins.	47,053	...	25	7,401	2,408	156	1,683	58,726	0 66	7 72	8 58	0 35	4 47	5 2
1874—1875	Wirral 4 ft. 8½ ins.	22,108	...	2,267	...	2,003	2,121	1,506	30,598	0 34	2 45	2 79	0 34	2 45	2 79
1881—1883	Wisbech and Upwell (G. E. Railway Co.)* 4 ft. 8½ ins.	31,367	...	...	4,800	2,485	971	...	39,623	0 31	7 30	7 61	0 31	7 30	7 61
1880—1881	Withington Local Bd.* 4 ft. 8½ ins.	9,945	...	...	...	...	2,000	33	11,978	0 64	2 45	3 20	0 41	0 58	[illegible]
1877—1881	Wolverhampton* 4 ft. 8½ ins.	74,382	...	2,236	...	4,558	3,391	566	85,12[illegible]	1 70	6 35	8 05	1 70	6 85	8 55
1883—1888	Wolverton and Stony Stratford.* 3 ft. 6 ins.	17,360	...	...	3,800	2,000	2,220	4,000	30,380	0 41	2 25	2 66	0 41	2 25	2 66
1887—1888	Wolverton and Stony Stratford (Deanshanger Extension.)* 3 ft. 6 ins.	15,000	...	...	...	...	...	...	15,000	0 10	1 94	2 3	0 13	1 54	1 67
1880—1882	Woolwich and South-East London. 3 ft. 6 ins.	63,021	...	4,920	...	2,385	1,612	...	71,938	1 74	3 3	4 77	1 74	3 3	4 77
1881—1882	Worcester 3 ft.	...	...	...	...	...	...	...	...	0 53	2 49	3 22	0 53	2 49	3 22
1873—1872	Wrexham District 3 ft.	5,860	...		...	258	1,880	802	8,800	0 3	6 27	6 30	0 3	3 22	3 25
1871—1885	Yarmouth and Gorleston 3 ft. 6 ins.	17,314	...	1,100	...	1,300	400	...	20,114	0 31	2 57	3 8	0 31	2 57	3 8
1879—1882	York* 4 ft.	14,500	Lump sum paid for complete undertaking						14,500	0 60	2 28	3 8	0 60	2 28	3 8
	Total, England & Wales	[illegible]	153,862	600,55[illegible]	385,108	332,13[illegible]	557,717	451,158	11,132,0[illegible]	52 37	25 31	77 71	14 31	138 15	152 44

TABLE NO. 2 (*continued*).—SCOTLAND.

Years in which acts were passed.	Name of tramway, and gauge. * Mechanical power authorised (subject in most cases to Board of Trade approval).	Capital expended.								Authorised length.			Length open.		
		On lines and works open.	On lines and works in course of construction.	On horses.	On locomotive engines.	On cars.	Legal and Parliamentary.	Sundries.	Total.	Double line.	Single line.	Total.	Double line.	Single line.	Total.
		£	£	£	£	£	£	£	£	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.	m. ch.
1872—1889	Aberdeen District* 4 ft. 8½ ins.	45,332	...	3,552	...	2,537	2,125	349	54,195	1 54	7 30	9 4	1 54	7 30	9 4
1872—1888	Dundee Street (Commissioners of Police).* 4 ft. 8½ ins.	48,732 14,164	... ...	... 2,270	... 5,882	... 2,113	... 1,440	... 630	48,732 26,499	3 63	1 68	5 51	3 63	1 68	5 51
1884—1888	Edinburgh Northern* 4 ft. 8½ ins.	135,394	Company cannot supply these details						135,394	3 50	0 32	4 2	2 42	0 7	2 49
1871—1883	Edinburgh Street* 4 ft. 8½ ins.	291,989	...	36,704	...	12,469	27,507	24,399	393,068	13 66	4 29	18 15	13 66	4 29	18 15
1877—1879	Glasgow and Ibrox* 4 ft. 7¾ ins.	9,418	...	421	...	767	2,201	18	12,825	1 41	0 3	1 44	1 41	0 3	1 44
1880—1886	Glasgow Corporation 4 ft. 7¾ ins.	295,703 ...	... ...	... 64,805	... ...	... 25,630	49,159 ...	... ...	344,862 90,435	29 51	1 43	31 14	29 49	0 48	30 17
1887—1888	Greenock and Port Glasgow 4 ft. 7¾ ins.	31,521	...	...	...	1,516	3,177	3,197	39,411	2 74	0 8	3 2	2 53	0 2	2 55
1871—1878	Greenock Street (Board of Police) 4 ft. 8½ ins.	29,156	...	...	...	...	2,256	...	31,412	2 18	0 29	2 47	2 18	0 29	2 47
1885—1886	Paisley* 4 ft. 7¾ ins.	15,389	...	1,457	...	980	840	582	19,248	0 62	1 54	2 36	0 43	1 37	2 0
1880—1881	Rothesay 4 ft.	15,308	...	755	...	1,196	2,716	1,698	21,673	0 46	1 64	2 30	0 46	1 64	2 30
1872—1873	Stirling and Bridge of Allan 4 ft. 6 ins.	14,000	...	500	...	750	...	...	15,250	0 43	2 68	3 31	0 9	3 20	3 29
1871—1889	Vale of Clyde* 4 ft. 7¾ ins.	67,241	...	684	5,867	3,060	53,927	3,155	133,934	4 3	0 8	4 11	3 61	0 30	4 11
		1,013,347	...	111,148	11,749	51,018	145,648	34,028	1,336,938	65 11	22 36	87 47	62 65	21 47	84 32

IRELAND.

1872—1889	Belfast Street 4 ft. 8½ ins.	237,467	...	20,700	...	13,860	...	...	272,027	9 11	9 0	18 11	9 11	9 0	18 11
1883—1884	Blackrock & Kingstown 5 ft. 3 ins.	17,300	...	1,280	...	1,098	2,616	742	23,036	0 63	1 27	2 10	0 63	1 27	2 10
Order of Lord Lieut. in Council, 1889.	Blessington and Poulaphuca* 5 ft. 3 ins.	...	...	...	...	...	...	...	...	—	4 44	4 44	—	—	—
1883—1884	Castlederg and Victoria Bridge* 3 ft.	16,347	...	...	2,550	3,344	668	...	23,109	0 6	7 6	7 12	0 6	7 6	7 12
Orders of Lord Lieut. in Council, 1881.	Cavehill and Whitewell* 4 ft. 8 ins.	7,758	...	...	2,098	818	354	555	11,623	0 3	3 27	3 30	0 3	3 27	3 30
Do., do., 1880—1887, and acts of 1883-4.	Dublin and Blessington* 5 ft. 3 ins.	83,846	...	...	5,000	3,365	5,000	...	97,211	0 50	15 18	15 68	0 50	15 18	15 68
Order of Lord Lieut. in Council, 1880.	Dublin and Lucan* 3 ft.	27,357	...	...	5,086	2,047	...	...	35,390	0 17	6 61	6 78	0 17	6 61	6 78
1878—1887	Dublin Southern Dist.* 5 ft. 3 ins. and 4 ft.	66,732	...	1,802	...	3,546	1,235	1,207	74,522	1 75	3 66	5 61	1 75	3 66	5 61
1871—1882, and Order of Lord Lieut. in Council, 1865.	Dublin United* 5 ft. 3 in.	425,131	...	31,358	...	29,495	9,504	125,913	621,431	23 64	9 21	33 7	23 54	9 21	32 75
1877—1878	Galway and Salt Hill 3 ft.	12,800	...	300	...	1,100	1,720	...	15,920	0 10	2 0	2 10	0 10	2 0	2 10
1880—1880	Giant's Causeway, Portrush, and Bush Valley* 3 ft.	23,475	...	...	2,850	2,460	3,000	1,247	33,032	0 60	8 0	8 60	0 60	8 0	8 60
Order of Lord Lieut. in Council, 1887.	Lucan, Leixlip and Celbridge* 3 ft.	5,400	...	...	...	...	1,000	...	6,400	...	5 20	5 20	0 27	1 50	1 77
Order of Lord Lieut. in Council, 1880.	Portstewart* 3 ft.	5,104	...	...	1,568	335	...	...	7,007	...	1 68	1 68	...	1 68	1 68
Order of Lord Lieut. in Council, 1885 & 1887.	Sydenham District (Belfast)* 3 ft.	5,495	...	...	...	...	315	215	6,025	0 24	1 34	1 58	0 24	0 57	1 1
Order of Lord Lieut. in Council, 1875. 39 & 40 Vict. c. 120.	Warrenpoint and Rostrevor*	5,693	...	78	...	...	137	...	5,908	...	3 24	3 24	...	3 24	3 24
	Total, Ireland	910,103	...	55,518	19,152	62,378	25,743	129,879	1,232,801	37 65	82 10	120 1	38 0	73 25	111 25
	Total, United Kingdom	10,327,517	153,862	827,584	116,007	965,542	727,138	618,065	13,735,760	455 33	1,430 6	1,885 39	415 10	533 5	948 21

TABLE No. 3.—RECEIPTS, WORKING EXPENDITURE, AND STOCK OF TRAM-

ENGLAND

Name of tramway.	Gross receipts.	Working						
		Maintenance of way and works.	Locomotive power.	Animal power.	Repairs and renewals of engines.	Renewals, &c., of horses.	Repairs and renewals of cars.	Traffic expenses.
	£	£	£	£	£	£	£	£
Accrington Corporation Haslingden Extension.	12,887	1,880	3,638	...	2,228	...	596	1,433
Alford and Sutton	—	Tramway closed. Company in liquidation.						—
Barrow-in-Furness	5,561	105	1,687	...	203	...	36	708
Barton, Eccles, Winton, and Monton Local Board.	—	Tramway leased. Traffic included in Salford Corpora-						
Bath	—	No return received.			—	—	—	—
Birkdale and Stockport	2,251	86	...	...	...	20	173	1,329
Birkenhead	—	No return received.			—	—	—	—
Birmingham and Aston Birmingham Corporation (portion).	23,569	1,423	3,300	603	3,469	85	984	2,151
Birmingham and Midland Birmingham Corporation (portion).	20,271	1,383	4,678	...	1,936	...	612	1,490
	74,584	6,402	20,245	...	7,074	...	1,744	7,691
Birmingham Central	33,419	304		20,217	...	1,181	1,281	3,944
Birmingham Corporation (portion).	25,212	148	Cable haulage 4,877	...	1,843	...	747	2,349
	133,215	6,854	25,122	20,217	8,917	1,181	3,772	13,987
Birmingham Corporation	—	Tramway leased. Traffic included in "Birmingham and						
Blackburn and Over Darwen	6,607	653	...	...	1,207	...	105	2,420
Blackburn Corporation	15,424	453	1,709	3,035	521	188	314	4,662
Blackpool Corporation	6,550	178	312	...	99	314	...	1,183
Bolton and Suburban	20,867	...	...	6,150	...	1,000	650	3,362
Bootle	—	Tramway leased. Traffic included in "Liverpool Cor-						
Bradford and Shelf	—	Tramway leased to Bradford and Shelf Tramways Com-						
Bradford Corporation	29,328	210	11,664	2,438	900	355	392	1,000
Bradford and Shelf	11,420	6..	1,805	...	919	...	...	3,045
Brentford and District	—	Not open for traffic.			—	—	—	—
Brighton and Shoreham (formerly Brighton District).	368	5	...	183	...	...	...	74
Bristol	—	—	—	—	—	—	—	—
Burnley and District	12,857	1,370	1,708	...	1,372	...	315	3,346
Bury, Rochdale, and Oldham Oldham Borough (portion)	35,171	2,178	14,961	...	5,666	...	945	4,843
Cambridge Street	3,754	523	...	...	...	263	183	1,315
Cardiff Cardiff District & Penarth Harbour.	42,541	709	...	15,626	...	1,800	2,340	12,349
Cardiff District and Penarth Harbour.	—	Tramway worked by Provincial Tramways Company.						
Chesham, Boxmoor, and Hemel Hempstead.	—	No return for traffic.				-	-	
Chester	6,340	117	...	1,705	...	347	484	1,205

WAYS IN THE UNITED KINGDOM FOR THE YEAR ENDING JUNE 30, 1890.

AND WALES.

Expenditure.							Net receipts.	Number of passengers conveyed (including season or composition ticket-holders.)	Number of miles run by cars.	Working stock.		
Direction and management.	Rent of offices, stables, and sheds.	Rates, taxes, and tolls.	Compensation for personal injury.	Legal and parliamentary.	Sundry.	Total.				Number of horses.	Number of locomotive engines.	Number of cars.
£	£	£	£	£	£	£	£					
450	1,235	282	10	88	...	11,88[illegible]	1,00[illegible]	1,778,63[illegible]	231,451	...	14	14
—	—	—	—	—	—	—	—	—	—	—	—	—
313	...	341	...	130	181	3,855	1,720	1,[illegible],200	153,318	...	7	8
tion Return.		—	—	—		—	—			—	—	—
—	—	—		—		—	—	—		—	—	—
105	50	12	...	60	24	1,8[illegible]	883	303,000	57,71[illegible]	[illegible]	...	12
—	—	—	—	—		—	—					—
877	121	626	107	141	347	14,234	9,36[illegible]	Cars, 3,828,150 Buses, 100,287	Cars, 332,9[illegible] Buses, [illegible]07	20	27	20
550	804	Included in prev. col.	179	90	552	12,283	8,[illegible]90	4,783,304	312,105	...	24	22
4,543	1,651	3,051	919	714	255	...	...	12,714,86[illegible]	1,106,553	...	79	64
		891	75	56	112	...	...	4,123,127	750,5[illegible]	432	...	50
		1,025	160	125	82	...	...	4,201,050	457,800	...	..	20
4,543	1,651	5,567	1,163	895	449	93,318	38,867	22,182,011	2,420,28[illegible]	432	79	134
Aston," "Birmingham and Midland," and "Birmingham Central," Returns.											—	—
573	95	109	616	56	286	6,630	2,071	1,107,202	158,077	...	10	15
565	323	302	320	30	700	12,552	2,872	2,423,020	319,01[illegible]	85	14	27
435	50	241	224	27	73	3,130	3,433	[illegible]	65,368	...	...	10
240	700	300	100	...	...	15,571	5,2[illegible]	2,5[illegible]	411,430	320	...	36
poration" Return.		—	—		—	—	—			—	—	—
pany, Limited. For traffic, see "Bradford Corporation" Return.										—	—	—
730	31	750	2,000	11	530	20,960	8,308	[illegible]	302,56[illegible]	60	25	37
Included in prev. col.	...	520	...	...	303	6,5[illegible]0	4,83[illegible]	2,500,040	170,810	...	11	11
	—	—	—	—	—	—	—			—	—	—
...	...	3	...	...	...	265	103	43,611	6,700	29	...	[illegible]
—	—	—	—	—	—		—					
528	70	305	466	14	...	9,582	5,275	1,5[illegible]7,831	1[illegible]6,100	...	14	13
1,208	376	775	...	14	674	30,018	4,533	4,992,30[illegible]	838,541	...	84	81
221	17	91	...	...	109	2,721	1,053	578,014	[illegible]	21	...	6
200	2,072	...	139	...	...	35,335	7,18[illegible]	9,583,9[illegible]	970,017	43[illegible]	...	47
Traffic included in "Cardiff" Return.							—	—	—	—	—	—
—	—	—	—	—	—	—	—	—				
362	...	234	9	3	157	4,623	1,717	593,728	2[illegible],503	71	...	11

TABLE NO. 3.—ENGLAND

Name of tramway.	Gross receipts.	Working						
		Maintenance of way and works.	Locomotive power.	Animal power.	Repairs and renewals of engines.	Renewals, &c., of horses.	Repairs and renewals of cars.	Traffic expenses.
	£	£	£	£	£	£	£	£
Chesterfield	—	No return received.			—	—	—	—
Coventry and District .	3,441	140	1,427	...	526	...	142	360
Croydon (formerly Croydon and Norwood).	9,3[illegible]	358	...	2,495	...	304	250	3,472
Derby	10,738	...	...	4,060	...	1,000	563	3,046
Dewsbury, Batley, & Birstal	6,110	682	1,177	30	561		300	800
Drypool and Marfleet .	2,883	112	1,411	...	28[illegible]	.	24	484
Dudley and Kingswinford .	—	Not open for traffic.			—	—	—	—
Dudley and Stourbridge .	9,371	408	2,007	...	1,014	...	228	958
Dudley, Sedgley, & Wolverhampton.	—	—	No return received.			—	—	—
Exeter	—	—	No return received.			—	—	—
Flamborough Head .	—	—	—	—	—	—	—	—
F'lkestone, Sandgate & Hythe	—	—	Not open for traffic.			—	..	—
Gateshead and District .	9,825	700	...	...	1,100	...	Included under Engines.	2,500
Gloucester	2,86[illegible]	71	...	877	...	172	5[illegible]	1,122
Gosport, Alverstoke, & Bury Cross.	—	—	Not open for traffic.			—	—	—
Gravesend, Rosherville, and Northfleet.	1,911	53	...	852	...	...	27	429
Great Grimsby. . . .	6,055	80	.	1,755	...	268	106	1,130
Harrow Road & Paddington	[illegible]	20	...	3,159	...	203	107	3,000
Hartlepools	1,5[illegible]	70	205	...	213	...	61	800
Highgate Hill . . .	—	—	No return received.			—	—	—
Huddersfield Corporation .	15,80[illegible]	1,746	4,201	...	1,803	...	840	1,487
Hull Street	13,9[illegible]	2,205	...	3,972	...	81	759	4,770
Ipswich	2,141	32	...	735	...	233	104	866
Keighley	1,833	...	...	825	...	59	41	600
Lancaster and District .	—	—	Not open for traffic.			—	—	—
Lea Bridge, Leyton, & Walthamstow.	—	—	—	—	—	—	—	—
Leamington and Warwick .	5,56[illegible]	640	...	2,408	...	250	274	399
Leeds	48,432	2,840	8,13[illegible]	4,723	Included in Col. 2.	1,375	3,637	6,345
Leeds Corporation . .	—	—	Not open for traffic.			—	—	—
Leicester	31,615	2,170	...	11,82[illegible]	...	1,000	2,217	7,855
Lincoln	2,012	2[illegible]	...	43[illegible]	...	53	75	509
Lincolnshire	—	—	Not open for traffic.			—	—	—
Liverpool Corporation . Bootle Corporation . Walton Local Board . Wavertree Local Board . West Derby Local Board	275,912	1,253	...	100,07[illegible]	...	13,286	15,076	48,707
Llanelly	98.	Worked in connection with another business, and can						
London	300,22[illegible]	22,142	...	86,418	...	13,550	7,087	69,703
London, Camberwell, & Dulwich.	—	—	—		—		—	—
London Southern . . .	14,71[illegible]	51[illegible]	...	5,512	...	640	499	4,503
London Street . . .	126,442	6,708	...	40,12[illegible]	...	4,904	3,401	38,309

AND WALES (*continued*).

Expenditure							Net receipts.	Number of passengers conveyed (including season or composition ticket-holders).	Number of miles run by cars.	Working stock.		
Direction and management.	Rent of offices, stables, and sheds.	Rates, taxes, and tolls.	Compensation for personal injury.	Legal and parliamentary.	Sundries.	Total.				Number of horses.	Number of locomotive engines.	Number of cars.
£	£	£	£	£	£	£	£	—	—	—		—
482	33	38	10	17	220	3,401	[illegible]	[illegible]	[illegible]	...	[illegible]	[illegible]
261	...	148	49	...	...	7,375	1,[illegible]	1,40[illegible]	[illegible]	[illegible]	...	[illegible]
306	185	233	...	...	55	[illegible]	1,001	2,454,[illegible]	[illegible]	[illegible]	...	[illegible]
200	60	324	...	...	...	4,131	1,[illegible]	1,3[illegible]	115,[illegible]	1		[illegible]
182	77	89	79	20	73	2,8[illegible]	[illegible]	[illegible]	[illegible]	...		[illegible]
—	—	—	—	—	—	—	—				—	—
25[illegible]	...	315	727	216	302	6,45[illegible]	2,916	2,1[illegible]	121,[illegible]	...		[illegible]
—	—	—	—	—	—	—	—	—		—		
—	—	—	—	—	—	—	—	—				
—	—	—	—	—	—	—	—	—			—	
—	—	—	—	—	—	—	—				—	
470	375	...	1,000	...	1,800	7,545	1,880	1,851,5[illegible]	[illegible]	...	[illegible]	[illegible]
110	73	Included in prev. col.	...	...	42	2,523	514	650,13[illegible]	[illegible]	...	...	[illegible]
—	—	—	—	—	—	—	—	—				
...	110	78	...	[illegible]	24	1,503	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
200	449	...	...	...	...	3,00[illegible]	2,05[illegible]	[illegible]	200,1[illegible]	[illegible]		[illegible]
456	150	131	...	...	...	7,85[illegible]	1,074	1,[illegible]	[illegible]	...		[illegible]
123	...	64	...	...	...	1,540	[illegible]	310,461	[illegible]			[illegible]
—	—	—	—	—	—	—	—	—	—	—		
528	154	37[illegible]	180	...	245	11,50[illegible]	[illegible]	[illegible]	[illegible]	...	[illegible]	[illegible]
187	24	381	27	[illegible]	...	12,66[illegible]	1,04[illegible]	3,119,[illegible]	[illegible]	[illegible]		[illegible]
50	30	48	...	...	73	2,11[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
...	13	80	...	...	78	1,751	[illegible]	[illegible]	[illegible]	[illegible]		
—	—	—	—	—	—	—	—			—	—	—
—	—	—	—	—	—	—		—		—		
150	71	115	...	2	313	4,622	[illegible]	713,03[illegible]	105,57[illegible]	[illegible]	...	[illegible]
850	608	870	...	131	1,065	35,[illegible]	12,[illegible]	7,5[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
—	—	—	—	—	—	—	—					
1,051	145	301	18	...	...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
78	...	111	...	3	16	1,[illegible]	[illegible]	118,[illegible]	[illegible]	[illegible]		
—	—	—	—						—			
3,085	2,233	6,285	697	902	1,617	103,21[illegible]	82,6[illegible]	Cars [illegible] Buses, [illegible]	Cars, [illegible] Buses [illegible]	[illegible]	—	[illegible]
not be stated		...	...	...	...	...		[illegible]	[illegible]	[illegible]	—	
5,715	4,05[illegible]	4,133	1,52[illegible]	1,206	3,510	22[illegible]	70,518	[illegible]	[illegible]	[illegible]	...	[illegible]
—	—	—	—	—	—	—	—					
357	457	...	133	...	...	12,61[illegible]	2,12[illegible]	2,[illegible]	[illegible]	[illegible]		20
1,500	4,79[illegible]	...	1,199	...	...	101,081	25,[illegible]	[illegible]	2,[illegible]	[illegible]		[illegible]

TABLE NO. 3.—ENGLAND

Name of tramway.	Gross receipts.	Working						
		Maintenance of way and works.	Locomotive power.	Animal power.	Repairs and renewals of engines.	Renewals, &c., of horses.	Repairs and renewals of cars.	Traffic expenses.
	£	£	£	£	£	£	£	£
Manchester Carriage and **Tramway Company.** Manchester Corp. (part Moss Side Local Board Newton Heath Local Bd. Oldham Borough (part) Withington Local Board	262,337	3,249	...	73,491	...	17,435	6,812	66,429
Manchester Corporation .	Tramways leased. Traffic included chiefly in "Manchester Car							
Manchester, Middleton, and District	Not open for traffic.			—	—	—	—	—
Middlesborough & Stockton	5,540	350	1,810	1,341		65	136	402
Morecambe	2,638	20		869		..	55	430
Moss Side Local Board .	Traffic included in "Manchester Carriage and Tramways Com							
Neath and District . .	—	—	—	—	—	—	—	—
Newcastle-upon-Tyne Corp.	30,471	590	...	11,550	...	1,174	1,537	4,020
Newport and Parkhurst	—	—	—	—	—	—	—	—
Newport (Mon.) . . .	4,498	220	...	869	—	123	307	1,083
Newport Pagnell & District	—	—	—	—	—	—	—	—
Newton Heath Local Board	Traffic included in "Manchester Carriage and Tramways Com							
Northampton Street . .	6,178	81	...	1,506	...	353	126	1,177
North London . . .	17,250	1,096	5,172	114	1,306		42	6,383
North Metropolitan . .	405,202	35,476	1,380	116,907		13,505	10,578	84,860
North Shields & Tynemouth District	Line only re-opened on 12th June, 1890.				—		...	...
North Staffordshire . .	17,027	677	[illegible]	30	102		158	5,418
Nottingham and District .	24,508	[illegible]	...	14,151	...	963	825	3,537
Oldham, Ashton-under-Lyne and Hyde District.	—	—		—		—	—	—
Oldham Boro' (Corporation)	Traffic included partly in "Bury, Rochdale, and Oldham" Ret							
Oxford (City of) and District	6,312	321	...	2,253	...	205	..	2,078
Plymouth	—	—	—	—	—	—	...	—
Plymouth, Stonehouse, and **Devonport.**	14,215	316	...	4,085	...	373	712	2,357
Pontypridd & Rhondda Valley	No return received. Company in liquidation.						—	—
Portsmouth (Boro' of) Kingston, Fratton, and Southsea.	Tramway worked in conjunction with the Portsmouth Street Tr							
Portsmouth Street . . Borough of Portsmouth, &c.	44,097	1,846	...	16,542	...	1,267	2,949	12,63
Preston Corporation and Fulwood Local Board.	10,721	.	...	3,072	..	...	366	1,049
Reading	5,020	426		1,781	...	190	323	390
Rossendale Valley . .	6,077	...	810	...	265	..	30	1,655
St. Helens and District .	3,045	250	400	300	20	...	16	270
Salford Corporation . Manchester Corporation (portion) Barton, &c., Local Board	49,014	...	...	20,086	...	4,907	2,055	19,002

AND WALES (*continued*).

Expenditure.							Net receipts.	Number of passengers conveyed (including season or composition ticket-holders.)	Number of miles run by cars.	Working stock.		
Direction and management.	Rent of offices, stables, and sheds.	Rates, taxes, and tolls.	Compensation for personal injury.	Legal and parliamentary.	Sundry.	Total.				Number of horses.	Number of locomotive engines.	Number of cars.
£	£	£	£	£	£	£	£					
5,319	2,423	4,502	1,655	537	3,665	188,821	73,518	39,502,100	6,181,440	2,790	...	303
riage and Tramways Co.'s" Return, but partly in "Salford Corporation" Return												—
—	—	—	—	—	—	—	—	—	—	—	—	—
446	20	157	...	...	31	4,804	737	Cars, 753,304 Ferry steamers 342,012	Cars, 114,193 Ferry steamers, 35,826	27	2	12
125	25	80	...	10	171	1,770	872	627,072	32,300	31	...	7
pany's" Return.			—	—	—	—	—		—			—
—	—	—	—	—	—	—	—	—	—	—	—	—
888	236	1,063	112	25	3,992	25,107	5,277	3,717,136	689,016	278	...	30
—	—	—	—	—	—	—	—	—	—	—	—	—
180	80	83	...	...	106	3,057	1,441	1,030,120	115,000	40	...	8
—	—	—	—	—	—	—	—	—	—	—	—	—
pany's" Return.			—	—	—	—	—	—	—			
504	...	54	...	...	175	4,046	2,132	1,238,745	131,493	58	...	14
630	76	623	874	220	64	10,100	641	1,773,700	245,221	[illegible]	25	27
9,302	3,285	10,605	7,166	Included in prev. col.	1,185	294,332	110,800	69,715,528	7,170,000	3,340	...	342
...	...	...	...	...	...	...	...	...	...	...	5	6
1,015	26	257	320	50	...	10,230	7,088	2,000,580	281,013	1	22	22
883	...	561	28	116	...	21,405	3,013	3,700,007	635,714	27	1	34
—	—	—	—	—	—	—	—	—	—			—
urn, and partly in "Manchester Carriage and Tramways Company's" Return.												
450	60	207	...	53	601	6,731	2,618	1,350,415	240,084	...	83	14
—	—	—	—	—	—	—	—	—	—	—	—	—
200	1,406	...	8	...	...	10,357	3,858	2,237,001	207,806	...	121	24
—	—	—	—	—	—	—	—	—	—	—	—	—
amways.		—	—	—	—	—	—	—	—			—
200	1,026	...	46	...	...	37,112	5,987	6,008,817	1,250,337	100	...	75
200	65	149	...	...	55	7,856	2,665	1,030,302	258,432	116	...	31
433	25	133	...	...	24	3,734	1,286	788,437	121,348	40	...	15
529	73	133	401	...	49	3,054	2,123	984,735	137,108		9	10
25	24	103	20	...	605	2,123	922	362,924	Hor. cars, 21,000 Stm. cars, 34,554	74	7	7
2,293	682	1,267	352	114	1,116	53,074	15,040	8,128,080	1,079,360	787	...	82

TABLE No. 3.—ENGLAND

Name of tramway.	Gross receipts.	Working						
		Maintenance of way and works.	Locomotive power.	Animal power.	Repairs and renewals of engines.	Renewals, &c. of horses.	Repairs and renewals of cars.	Traffic expenses.
	£	£	£	£	£	£	£	£
Sheffield Corporation	30,202	4,774	...	14,346	...	1,825	1,150	3,520
Shipley	1,301	110	...	.	...	...	...	1,247
Southampton Street	13,752	645	...	3,703	...	310	847	5,549
South Eastern Metropolitan	No return received.			—		—	—	—
South Gosforth	6,738	107	...	4,002	.	235	220	1,570
South London	74,[illegible]	4,174	...	...	...	3,704	4,373	10,057
Southport	10,[illegible]	583	...	2,361	...	288	247	1,413
South Shields Corporation	5,032	.	...	2,318	...	266	413	802
South Staffordshire (formerly South Staffordshire and Birmingham District).	22,263	1,656	4,971	603	3,293	...	864	5,620
Southwark and Deptford	24,474	1,013	...	5,416	...	1,718	658	8,840
Stockport and Hazel Grove	1,047	...	...	225	..	10	7	224
Stockton-on-Tees and Dist	5,252	102	360	801	270	137	54	2,375
Sunderland (Company's)	15,184	1,282	...	4,416	...	584	1,159	1,269
Sunderland (Corporation)	Tramways leased. Traffic included in "Sunderland(Com							
Swansea	22,027	1,174	1,074	4,075	657	548	732	2,557
Wallasey	4,043	158	...	1,282		301	240	1,204
Walton-on-the-Hill Local Board	Tramways leased. Traffic included in "Liverpool Corpor							
Wantage	1,787	58	...	...	200	...	18	860
Wavertree Local Board	Tramways leased. Traffic included in "Liverpool Corpor							
West Derby Local Board	Tramways leased. Traffic included in "Liverpool Corpor							
West Metropolitan	20,017	3,343	...	6,420	...	781	786	8,440
Weston-super-Mare, Clevedon, and Portishead	Not open for traffic.			—	—	—	—	—
Wigan	7,828	608	2,354	16	876	.	233	553
Wirral	5,780	337	...	1,294	...	381	170	1,458
Wisbech and Upwell (Great Eastern Railway Company)	2,301	314	685	...	242	...	1,048	450
Withington Local Board	Tramways leased. Traffic included in "Manchester Carri							
Wolverhampton	10,508	526	...	3,258	...	405	332	924
Wolverton and Stony Stratford	2,042	302	725	150	322	...	136	469
Wolverton and Stony Stratford. (Deanshanger Extension)	Tramways leased. Traffic included in "Wolverton and Sto							
Woolwich and South East London	14,[illegible]	485	...	3,841	...	702	445	5,050
Worcester	No Return received.			—	—	—	—	—
Wrexham	856	72	...	240	..	20	40	205
Yarmouth and Gorleston	5,2[illegible]	370	...	1,8[illegible]	...	100	82	651
York	3,600	63	...	1,[illegible]		...	70	1,129
Total, England and Wales	2,573,535	130,110	110,054	660,387	40,350	102,114	93,600	552,793

AND WALES *(concluded)*.

Expenditure.							Net receipts.	Number of passengers conveyed (including season or composition ticket-holders.)	Number of miles run by cars.	Working stock.		
Direction and management.	Rent of offices, stables, and sheds.	Rates, taxes, and tolls.	Compensation for personal injury.	Legal and parliamentary.	Sundry.	Total.				Number of horses.	Number of locomotive engines.	Number of cars.
£	£	£	£	£	£	£	£					
1,000	362	1,495	...	13	304	28,780	10,413	6,185,570	[illegible]	[illegible]	...	40
							Loss.					
193	100	95	...	207	56	2,008	617	[illegible]	[illegible]	20	...	5
475	360	...	6	...	...	11,955	1,777	[illegible]	[illegible]	[illegible]	...	20
—	—	—	—	—	—	—	—	—	—	—	—	—
350	250	60	70	200	172	7,232	2,500	[illegible]	[illegible]	[illegible]	...	11
1,055	954	655	913	205	26,995	63,647	[illegible]	[illegible]	[illegible]	[illegible]	.	86
476	59	224	...	...	101	5,815	4,243	1,145,117	[illegible]	[illegible]	...	23
323	16	100	503	...	226	5,000	612	[illegible]	[illegible]	[illegible]	...	8
1,460	114	550	...	97	722	10,950	2,343	[illegible]	[illegible]	[illegible]	30	31
889	201	258	337	161	260	19,745	4,720	[illegible]	[illegible]	[illegible]	...	32
...	24	...	...	...	61	503	482	[illegible]	[illegible]	[illegible]	...	6
144	67	121	113	3	...	4,554	698	[illegible]	[illegible]	[illegible]	8	15
730	25	225	2	...	132	9,885	[illegible]	[illegible]	[illegible]	[illegible]	...	33
pany)	" Return.		—	—	—	—	—	—				
1,035	355	1,075	10	323	270	14,821	[illegible]	[illegible]	[illegible]	[illegible]	.	[illegible]
300	...	121	...	26	330	4,101	843	[illegible]	[illegible]	[illegible]	.	8
ation	" Return.		—	—	—	—	—	—	—		—	—
25	...	25	...	...	...	1,181	[illegible]	[illegible]	[illegible]	...	[illegible]	[illegible]
ation	" Return.		—	—	—	—	—	—	—			
ation	" Return.		—	—	—	—	—	—	—		—	
724	300	502	284	44	..	21,640	[illegible]	[illegible]	[illegible]	[illegible]	...	38
—	—	—	—	—	—	—	—				—	
310	...	360	455	300	130	6,103	1,635	[illegible]	[illegible]	1	12	12
457	...	205	...	43	252	4,034	1,140	763,752	[illegible]	17	...	7
Included in direction and management of railway.	...	77	...	...	8	2,824	Loss. 52[illegible]	[illegible]	[illegible]	...	3	6
age and Tramway Company's " Return.							—					
600	195	300	33	13	180	6,925	3,583	1,527,825	[illegible]	[illegible]	...	20
							Loss.					
236	31	58	...	...	363	2,840	80[illegible]	[illegible]	[illegible]	2	4	6
ny Stratford " Return.				—	—	—	—					
844	95	181	16[illegible]	...	111	11,920	3,014	[illegible]	[illegible]	110	[illegible]	15
—	—	—	—	—	—	—	—	—	—	—	—	—
32	10	6	...	...	...	633	222	[illegible]	[illegible]	[illegible]	...	[illegible]
266	54	146	...	9	233	4,023	[illegible]	850,027	[illegible]	[illegible]	.	[illegible]
136	96	...	...	...	48	2,000	[illegible]	[illegible]	[illegible]			16
65,107	36,616	51,901	24,905	6,957	56,932	1,032,444	[illegible]	[illegible]	[illegible]	[illegible]	501	[illegible]

TABLE No. 3 (*continued*).—

Name of tramway.	Gross receipts.	Working						
		Maintenance of way and works.	Locomotive power.	Animal power.	Repairs and renewals of engines.	Renewals, &c., of horses.	Repairs and renewals of cars.	Traffic expenses.
	£	£	£	£	£	£	£	£
Aberdeen District	16,370	623	...	5,730	...	...	722	3,558
Dundee Street (Commissioners of Police)	15,669	1,042	2,376	...	1,275	424	626	4,094
Edinburgh Northern	4,767	1,635	959 (Cable.)	694	Included in first col.	...	Included in first col.	2,170
Edinburgh Street	103,470	6,371	...	31,820	...	4,301	3,833	13,014
Glasgow and Ibrox	1,191	92	...	591	...	58	101	357
Glasgow Corporation	251,180	1,582	...	91,507	...	19,140	5,718	37,829
Greenock and Port Glasgow	5,733		...		...	...	24	2,560
Greenock Street (Board of Police)	Return.	Traffic	included in	"Vale	of	Clyde"	returns.	—
Paisley	2,911	...	...	645	...	99	85	903
Rothesay	3,305	121	...	643	...	97	87	553
Stirling and Bridge of Allan	2,324	205	..	1,123	...	...	158	295
Vale of Clyde Greenock Street	16,717	614	2,501	1,802	2,113	256	Included with engines.	1,433
Total Scotland	[illegible]	12,286	5,836	153,643	5,338	24,431	11,335	62,576

IRELA

Name of tramway.	Gross receipts.	Maintenance of way and works.	Locomotive power.	Animal power.	Repairs and renewals of engines.	Renewals, &c., of horses.	Repairs and renewals of cars.	Traffic expenses.
Belfast Street **Sydenham District**	71,042	1,717	...	22,404	...	1,803	2,532	19,470
Blackrock and Kingstown	2,043	2	...	674	.	126	41	813
Blessington and Poulaphuca	—	Not open for traffic.			—	—	—	—
Castlederg & Victoria Bridge	1,094	168	343	...	...	...	15	427
Cavehill and Whitewell	2,312	233	640	...	790	...	...	220
Dublin and Blessington	4,791	623	1,531	...	210	...	15	575
Dublin and Lucan **Lucan, Leixlip, & Celbridge**	4,837	418	639	...	570	...	185	650
Dublin Southern District	7,340	674	...	3,110	...	446	797	1,061
Dublin United	123,150	16,791	...	32,321	...	5,120	5,233	22,210
Galway and Salt Hill	1,353	47	...	395	...	...	81	422
Giant's Causeway, Portrush, and Bush Valley	2,140	183	792	...	305	...	60	284
Lucan, Leixlip & Celbridge	Worked by "Dublin and Lucan Steam Tramway Company," and							
Portstewart	683	3	351	...	...	...	27	68
Sydenham District (Belfast)	Tramway worked by "Belfast Street Tramway Company," and							
Warrenpoint and Rostrevor	1,134	32	...	272	...	39	30	257
Total Ireland	223,858	23,625	4,928	59,145	1,754	7,540	6,015	46,417
Total United Kingdom	[illegible]	192,539	121,417	854,224	45,672	131,083	113,059	661,786

SCOTLAND.

Expenditure.										Working stock.		
Direction and management.	Rent of offices, stables, and sheds.	Rates, taxes, and tolls.	Compensation for personal injuries.	Legal and parliamentary.	Sundry.	Total.	Net receipts.	Number of passengers conveyed (including season or composition ticket-holders.)	Number of miles run by cars.	Number of horses.	Number of locomotive engines.	Number of cars.
£	£	£	£	£	£	£	£					
465	78	243	...	...	282	11,701	4,075	1,062,310	310,354	11[illegible]	.	1[illegible]
466	...	344	298	19	1,027	12,501	3,498	Cars. 2,347,130 'Buses, 450,211	Cars, 424,358 'Buses, 14,519	77	10	18
1,030	...	755	...	...	...	6,705	3,103	1,899,228	192,487	...	Cable traction.	14
2,060	877	2,620	356	465	2,271	68,948	34,526	14,829,782	1,501,253	902	...	79
79	65	11	...	...	...	1,127	31	272,730	45,[illegible]	12	...	4
3,350	...	6,844	1,585	400	13,241	176,005	65,181	47,769,191	4,333,[illegible]	2,687	...	213
...	125	35	11	11	30	2,570	1,157	615,4[illegible]	86,[illegible]	66	...	11
—	—	—	—	—	—	—	—	—	—	—	—	—
58	200	4[illegible]	...	...	32	2,234	677	545,365	77,1[illegible]	33	...	6
107	50	256	2	...	72	2,050	1,255	422,[illegible]	58,458	2[illegible]	...	14
100	...	131	2	...	155	2,159	565	303,808	47,141	23	...	7
712	258	516	41	130	74	10,581	6,127	3,439,055	209,[illegible]	36		21
8,285	1,583	11,054	2,207	1,023	17,782	306,19[illegible]	120,857	76,068,51[illegible]	7,255,[illegible]	3,120	[illegible]	421

1,000	781	...	76	...	...	49,783	22,150	13,732,855	1,[illegible]	6[illegible]	...	5[illegible]
104	48	85	...	...	90	1,983	60	26[illegible]	[illegible]	20	...	6
—	—	—	—	—	—	—	—	—	—	—	—	—
200	...	57	...	...	78	1,388	658	[illegible]	1[illegible]	...	2	5
50	16	50	134	...	25	2,165	1[illegible]	21[illegible],141	55,628		[illegible]	4
115	88	50	5	50	338	4,170	552	133,[illegible]	8[illegible]		6	[illegible]
201	26	63	7	...	225	3,311	1,525	222,[illegible]	5[illegible]	...	5	11
495	30	153	15	5	64	6,850	490	678,[illegible]	18[illegible]	8[illegible]	...	28
2,965	782	4,454	625	1,201	5,10[illegible]	99,818	23,5[illegible]	16,203,1[illegible]	2,5[illegible]	1,[illegible]		1[illegible]1
71	54	54	...	...	76	1,172	281	192,5[illegible]	47,[illegible]	1[illegible]	...	7
171	12	15	...	...	...	1,822	315	63,947	[illegible]	[illegible]		15
traffic included in that Company's return.							—	—	—	—	—	—
57	3	11	...	...	..	525	1[illegible]1	63,612	10,[illegible]	...	[illegible]	3
traffic included in that Company's return.							—	—	—	—	—	—
161	39	30	...	5	5	8[illegible]	280	6[illegible],11[illegible]	[illegible]	6	...	9
5,864	1,870	5,022	860	1,25[illegible]	6,027	173,89[illegible]	49,995	3[illegible]	[illegible]	1,[illegible]	[illegible]	[illegible]
70,280	49,078	67,987	27,972	9,241	80,741	2,[illegible]	811,[illegible]13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE NO. 4.—TOTAL WORKING EXPENDITURE ON ALL THE TRAMWAYS OF THE UNITED KINGDOM FOR THE YEARS ENDING JUNE 30, 1890, AND JUNE 30, 1880.*

For year ending June 30.	1890.			1880.		
Items.	Working expenditure.	Per mile open.	Per cent. of total expenditure.	Working expenditure.	Per mile open.	Per cent. of total expenditure.
	£	£	Per cent.	£	£	Per cent.
Maintenance of way and works	166,330	176	6·93	65,466	178	5·88
Locomotive power	121,417	129	5·06	3,189	9	·29
Horsing, or animal power	854,226	903	35·59	501,506	1,363	45·05
Repair and renewal of engines	45,692	49	1·90	—	—	—
Repair and renewal of cars	113,959	110	4·75	48,947	133	4·40
Renewal of horses	134,085	143	5·59	—	—	—
Traffic expenses	661,786	702	27·57	299,121	813	26·87
Direction and management	79,286	84	3·30	43,109	117	3·88
Rent of tramways (offices, stables, and sheds) ...	40,078	42	1·67	40,525	110	3·64
Rates, taxes, and turnpike tolls	67,987	72	2·83	39,782	108	3·57
Compensation for personal injury	27,972	29	1·06	10,245	28	·92
Legal and parliamentary	9,241	10	·38	15,853	43	1·42
Sundry	80,741	86	3·36	45,351	123	4·07
Totals	2,402,800	2,535	100·00	1,113,094	3,024	100·00

In 1869—71 the North Metropolitan and the tramways constituting the London Tramways Company were authorised to lay various lines in the north, south, and east of London. In the beginning of 1873 a total length of 42 miles of tramway had been opened in the streets of the metropolis; the length was increased to 61 miles in 1876, and to 120 miles in 1891.

Acts were applied for and obtained, authorising the construction of tramways in many cities and towns in the provinces; and at June 30, 1892, the lengths of line open for public traffic were:—

	Miles open, June 30, 1892.
England and Wales	750
Scotland	84
Ireland	112
United Kingdom	946

---

* For the Total Working Expenditure for the year ending June 30, 1893, see Appendix C (p. 729).

Nearly 1,000 miles, or an average of 43 miles per year for twenty-two years. From this remarkable expansion of tramway lines to meet the wants of the public, one is prepared to find that tramway conveyance has been correspondingly developed. It has been estimated that in London alone 200,000,000 of tramway passengers were conveyed in the year 1891. The relative importance of this volume of traffic is indicated by the following gross totals:—

METROPOLITAN TRAFFIC:—PASSENGERS, 1891.

Railway passengers	327 millions.
Omnibus ,, ...	200 ,,
Tramway ,, ...	200 ,,
Cab and steamer passengers . .	50 ,,
Total . .	777 millions.

Showing that upwards of one-fourth of the whole metropolitan passenger traffic was conveyed by tramways: a traffic which has sprung into existence in the course of about twenty years.

Nevertheless, there are signs of an abatement of the expansion of traffic in the tramway systems of the country, taken together, in the following returns for the years 1891 and 1892:—

Year ending	June 30, 1891.	June 30, 1892.	Increase or decrease.
			Per cent.
Total capital expended . .	£14,162,650	£13,870,234	− 2·0
Length of line open for public traffic.	963 miles	946 miles	− 1·8
Number of horses . . .	29,012	29,699	+ 2·3
Number of locomotives . .	579	534	− 7·8
Number of cars . . .	4,067	4,020	− 1·1
Total number of passengers carried	565,621,478	581,678,546	+ 2·9
Number of miles run by cars .	67,934,004	70,018,365	+ 3·0
Gross receipts . . .	£3,429,686	£3,531,431	+ 3·0
Working expenses . .	£2,630,929	£2,853,356	+ 8·4
Do. per cent. of gross receipts	76·5	80·8	
Net receipts	£798,577	£678,075	− 15·0
Do. per cent. of gross receipts	23·5	19·2	

In this statement it appears that though the car mileage run, the number of passengers, and the gross receipts in the year ended June 30, 1892, were greater than in the previous year, yet there was a reduction of the net receipts. There was actually a decrease of 17 miles in the length of line open for public traffic. The number of horses is somewhat larger, but locomotives are fewer by forty-five and cars by forty-seven. The amount of capital has also shrunk: by transfer of old undertakings to new with reduced capital.

The tramways of London taken together supply instances of very various lengths and costs. They embrace a total length of over 130 miles, of which 127¼ miles were open for traffic at June 30, 1891, as detailed in the following Table, No. 5:—

TABLE NO. 5.—SUMMARY OF TRAMWAYS IN LONDON:—COMPARATIVE LENGTHS, CAPITAL, AND RECEIPTS, FOR THE YEAR ENDING JUNE 30, 1891.

Name of tramway company.	Length open.	Capital expended.	Capital expended per mile open.	Gross receipts.	Miles run by cars.	Working expenses.	Net receipts.	Net receipts per mile open.	Net receipts per cent. of capital.
	m. ch.	£	£	£	miles.	£	£	£	per cent.
North Metropolitan * . .	41 73	1,390,888	33,185	415,316	7,409,120	310,880	104,436	2,485	7·48
London	22 20	652,885	28,219	315,729	7,522,710	252,846	62,883	2,802	9·63
London Street . . .	13 40	434,608	32,193	130,242	2,468,381	107,220	23,022	1,705	5·26
South London . * . .	12 72	368,130	28,537	74,381	1,752,226	70,575	3,806	295	1·08
West Metropolitan . .	8 59	208,000	23,805	26,598	664,885	24,527	2,071	238	·97
North London * . . .	9 73	183,261	18,360	14,297	185,014	18,681	Loss 4,384	Loss 442	Loss 2·14
Southwark and Deptford .	4 72	167,314	34,146	24,583	524,066	20,740	3,843	784	2·41
London Southern . . .	5 60	111,870	19,456	15,471	462,349	12,878	2,593	494	2·63
Highgate Hill	— 57	21,991	30,847	3,974	84,767	3,815	159	223	·07
Harrow Road & Paddington	1 61	75,159	42,643	10,025	211,565	7,791	2,234	1,269	4·10
Woolwich & S. E. London .	4 77	73,637	14,583	15,293	322,671	12,368	2,925	694	4·05
Totals . . .	127 24	3,687,743	28,968	1,045,909	21,607,754	842,321	278,598	2,188	7·56
Lond., Camberwell, & Dulwich	3 20	30,150	9,276	Not	open for	traffic.			

* About to be amalgamated.

CHAPTER II.

CAPITAL, RECEIPTS, & WORKING EXPENDITURE OF THE NORTH METROPOLITAN TRAMWAYS.

THE North Metropolitan Tramways is the largest system in the United Kingdom, 49 miles in length; next in order of length being the Bury system, 33¾ miles, the Dublin United, about 33 miles, and the Glasgow Corporation, about 30¼ miles in length. The receipts are one-fifteenth of the total receipts for the tramways of the United Kingdom. The North Metropolitan was opened on May 9, 1870. The horse power was hired from the London General Omnibus Company. The sum of 6¾d. per mile run by cars was paid for horse hire, which included the cost for maintenance, wear and tear, and renewal of horses, wages of keepers, rent of stables, and harness. In short, as Mr. Hopkins, the engineer to the Company, briefly put it, the horses were brought to the cars, harnessed, and worked for 6¾d. per mile run. This contract was terminated at the end of June, 1878, when the Tramway Company commenced to work the traffic with a stock of horses of their own. Under the contract each car on duty generally performed 70 miles-run per day, and required an active stud of eleven horses, of which five pairs were on duty with the car daily, leaving one spare horse. By the terms of the contract each pair of horses was not to work less than 14 miles nor more than 16 miles in one day. For five pairs of horses the mileage traversed was from 70 to 75 miles per day, or, for 5½ pairs of horses, 12¾ miles per pair per day. Horses were put to the work at five years of age, and the "life" of a horse on tramway work, according to Mr. A. G. Church, who was Secretary and Manager of the Omnibus Company, was four years.

The state of the total capital expenditure at the ends of the three years 1889, 1890, and 1891 was as follows, showing an expenditure at the rate of upwards of £31,000 per mile open:—

CAPITAL EXPENDITURE, 1889—1891.

Year.	Miles open at Dec. 31.	Lands, buildings, way, &c.	Working stock.	Horses.	Total.	Total per mile open.
		£	£	£	£	£
1889	41	1,127,153	60,550	116,983	1,304,686	31,821
1890	41	1,174,711	62,830	124,791	1,362,332	33,227
1891	49	1,213,014	66,430	133,032	1,412,476	31,388

In October, 1891, the purchase of the North London Tramways by the North Metropolitan Company was sanctioned by the shareholders, so bringing up the working length of the system from 41 miles to 49 miles.

The way, 49 miles in length, was double line, with the exception of 4¾ miles of single way, at the end of 1891.

The return of working stock, as at December 31, 1891, was as follows:—

ROLLING STOCK AND HORSES, DECEMBER 31, 1891.

Fully equipped street cars to carry 52 passengers each	35	
,, ,, 50 ,,	4	
,, ,, 46 ,,	271	
,, ,, 40 ,,	62	
,, ,, 20 ,,	4	
		376
Omnibuses to carry 26 passengers each		12
Carts, traps, vans, and trolleys		64
Water-carts		25
Forage vans		10
Brakes		2
Horse conveyances		2
Total rolling stock		491
Horses		3,587

It appears that much the greatest number of the cars—72 per cent.—were constructed to carry 46 passengers each. Next in numerical order are the cars for holding 40 passengers—16½ per cent.

The number of cars per mile open was 7·67.

The numbers of cars in good order and under repair in the three years 1889—91 were as follows:—

CARS IN 1889-91.

Year.	In good order at Dec. 31.	Under repair at Dec. 31.	Total to Dec. 31.
1889	322	20	342
1890	336	16	352
1891	355	21	376
Averages	338, or 94·7 %	19, or 5·3 %	357

Ten years earlier 88 per cent. of the existing stock at that time were in good order, and 12 per cent. were under repair. Twenty cars were purchased at the rate of £150 each.

The stock of horses required to work the traffic numbered 3,587 at December 31, 1891; or at the rate of 73·20 horses per mile open. The disposition of the horses was as follows:—

HORSES AT THE ENDS OF THE LAST SIX HALF-YEARS TO DECEMBER, 1891.

End of half-year.	In good condition.	Sick.	Lame	Total.	Died in ½-year.	Sold in ½-year.	Together.
June, 1889	3,027	21	101	3,149	118	123	241
Dec., 1889	2,963	58	105	3,126	176	115	291
June, 1890	3,239	24	83	3,346	156	134	290
Dec., 1890	3,147	97	111	3,355	214	109	323
June, 1891	3,444	60	86	3,590	243	69	312
Dec., 1891	3,386	59	142	3,587	315	95	410
Averages	3,201	53	105	3,359	204	107	311

It is seen that of the average total number of horses, 95·3 per cent. were in good condition, and 4·7 per cent. disabled: say, in round numbers, 95 per cent. and 5 per cent. respectively.

With respect to renewals of horses it may be taken, for purposes of calculation, that the horses provided for the augmentation of the stock in the course of the three years, from 3,149 to 3,587, by 438 horses, lived through this short period; and on this assumption the total deaths and sales of horses, as shown in the statement, 1,867 in number, are to be charged to the normal number of horses, 3,149. They make 59 per cent. of this number for three years' work, or 20 per cent. per year. At this rate the stock is entirely replaced in the course of five years, indicating that the working life of the stock is five years. Four hundred and seven horses were purchased at the average rate of £36 10s. each.

The miles run by cars, the receipts, and the number of passengers are stated in the following tablets:—

MILES RUN, RECEIPTS, PASSENGERS, IN THE THREE YEARS 1889—1891.

Year.	Miles run by cars.	Receipts from traffic.	Sundry receipts.	Total receipts.	Per cent. of capital expended.
		£	£	£	Per cent.
1889	7,101,107	380,497	12,716	393,213	30·1
1890	7.366,668	399,699	14,986	414,685	30·4
1891	7.523,879	414,313	16,515	430,828	30·5

Year.	Average length of way open	Receipts per average mile open.	Receipts per mile per week.	Receipts per car.	Receipts per mile run.
	Miles.	£	£	£	d.
1889	41	9,280	178·5	1,113	12·85
1890	41	9.749	187·5	1,136	13·1
1891	45	9.207	177·06	1,102	13·15

Year.	Number of Passengers.			Receipts from passengers.	
	Total.	Per car.	Per mile run.	Total.	Per passenger.
				£	d.
1889	66,458,568	194,323	9·4	380,497	2·74
1890	72,061,532	204,720	9·8	399,699	2·64
1891	75.323.550	200,329	10·05	414,313	2·64

The working expenditure for the three years 1889—91 is given in the annexed tablet. The last two columns are added to show the several expenses in parts of the total expenditure in 1891, with the costs per mile run by cars for each item.

WORKING EXPENDITURE, 1889—91.

Item.	1889.	1890.	1891.	1891. Proportional parts of total expenditure.	1891. Expenditure per mile run.
DIRECT EXPENDITURE.	£	£	£	Per cent.	Pence.
Running expenses:—					
Horsing . .	130,226	137,250	160,244	46·34	4·85
Wages of drivers and pole-shifters	31,374	34,780	38,004	12·56	1·21
Repair of cars .	10,732	10,114	10,545	3·55	·33
Maintenance of way	25,172	29,369	25,090	8·50	·80
Traffic charges .	49,239	53,861	60,046	17·95	1·91
General charges .	9,021	9,440	11,367	3·59	·36
Rent . . .	2,916	3,111	2,852	·84	·09
Direct .	258,680	277,925	308,148	93·33	9·55
CONTINGENT EXPENDITURE.					
Rates and taxes .	10,609	10,933	13,179	3·94	·42
Licenses and excise duties . . .	1,235	970	983	·29	·03
Compensation and law charges . .	9,791	7,951	8,504	2·44	·27
Contingent .	18,635	19,854	22,666	6·67	·72
TOTAL EXPENDITURE .	277,315	297,779	330,814	100·00	10·27
Do. per mile open .	6,764	7,263	7,351	—	—
	d.	d.	d.		
Do. per mile run .	9·39	8·34	10·37	—	—
Do. per cent. of receipts . . .	70·56%	71·79%	76·00%	—	—

The comparatively high rate of expenditure in 1891 was due to the rise in the price of forage, increase of wages, and unfavourable weather. The running expenses for the last half-year are detailed as follows :—

RUNNING EXPENSES, HALF-YEAR DECEMBER, 1891.

				s.	d.	£	Per mile run.
Maize	8,928½	quarters	@	28	1¼	12,549	
Oats	16,695	,,	@	17	10¼	14,906	
Beans	1,243	,,	@	34	5¾	2,140	
Bran	1,230	cwts.	@	5	9	354	
Peas	2,604½	quarters	@	32	0½	4,173	
Hay	2,829½	loads	@	66	0½	9,346	
Straw	810½	,,	@	34	8½	1,408	
Moss litter						1,339	
Sundries						151	
Barging						637	
						47,003	= 2·89d.
Stable wages and expenses						16,481	= 1·01
Granary wages and expenses						2,943	= 0·18
Repairs to harness						1,448	= 0·09
Shoeing						3,123	= 0·19
Horse depreciation and renewal						14,209	= 0·87
Electric haulage						879	= 0·05
						86,088	= 5·31
Drivers and pole-shifters' wages						21,013	= 1·29
						107,101	= 6·60

The item of horse depreciation and renewal is constituted in this way :—The loss on 315 deaths was £11,683, less the amount received for carcases, £474 ; say, £11,209. The loss on 95 cast horses sold was £3,523, less £523 the "scrap value," the net amount received for the same, leaving £3,000. The sum of the losses is £14,209 for 410 horses.

The receipts for manure during the half-year were £512, and deducting this sum from the cost for forage, leaving £46,491, the horsing expenses per horse are as follows, taking for divisor the mean of the numbers of horses at June 30 and December 31, 1891, say, 3,589 horses :—

HORSING EXPENSES PER HORSE PER WEEK IN HALF-YEAR DECEMBER, 1891.

Per horse.	Half-year ending Dec. 31st, 1891.			Per week.	
	£	s.	d.	s.	d.
Provender	12	19	1	9	11½
Stable wages and expenses	4	11	10	3	6
Granary ,, ,,	0	16	4		7½
Repairs to harness	0	8	7		4
Shoeing	0	17	5		8
Loss by depreciation and renewals	3	19	2	3	0
Total actual cost	23	12	5	18	1

Showing that the cost for horsing was upwards of £23 in the half-year, or £47 in the year, per horse, or 18s. per week per horse.

With respect to the cost for repair and maintenance of cars, particulars of which with mileage-run are subjoined, it appears that the average annual mileage-run is, say, 20,000 miles per car, or 57 miles per day; and that the average annual cost for maintenance and repair is about £30 per car, or ·34d., say ⅓d., per mile run.

MILEAGE-RUN AND REPAIR OF CARS, 1889–91.

Year.	Average number of cars.	Miles run by cars.			Cost for repairs.		
		Total.	Per car.		Total.	Per car.	Per mile run.
			Total.	Per day of 365.			
	Cars.	Miles.	Miles.	Miles.	£	£	Pence.
1889	338	7,101,107	21,009	57·55	10,732	31·38	·36
1890	347	7,366,668	21,229	58·16	10,114	28·73	·33
1891	366	7,523,879	20,557	56·32	10,545	28·04	·33
Averages			20,930	57·34	—	29·38	·34

With respect to maintenance of way, of which particulars of cost are given in the annexed tablet, the way has been and is in course of reconstruction with steel girder rails, and these expenses are taken as fairly measuring the cost for maintenance and renewal in perpetuity.

MAINTENANCE AND RENEWAL OF WAY, 1889—91.

Year.	Average length open.	Cost for maintenance and renewal of way.			
		Total.	Per mile of way.	Per sq. yard of way.*	Per mile run by cars.
	Miles.	£	£	Pence.	Pence.
1889	41	25,172	614	14·75	·85
1890	41	29,369	716	17·18	·94
1891	45	25,090	558	13·39	·80
Averages.	—	—	629	15·11	·86

* Allowing 10,000 square yards per lineal mile.

It thus appears that the cost for maintenance and renewal averages, say, £630 per mile per year, or 15d. per square yard of way, or ·86d. or ⅞d. per mile run by cars.

The Barking Road section of the tramways has been worked since the middle of 1889 by electric traction, under a contract made with the General Electric Power and Traction Company, who work the line at a charge of 4½d. per mile run, in which the wages of drivers are included. The Barking Road section is a short single line of way, with loops, requiring only a low mileage-run with a small number of cars. It does not offer such facilities for economy of working as would be available on a longer line. Even so, the given rate is less than the average cost per mile for horse traction. At the end of 1889 the electric cars had run 34,366 miles, having carried 469,095 passengers. In the year 1890 they ran 77,841 miles, and in 1891 they ran 76,398 miles. They ceased running in 1892. There were five electric cars, which ran 300 miles daily, or 60 miles per car, with one change of accumulators.

CHAPTER III.

CAPITAL, RECEIPTS, AND WORKING EXPENDITURE OF THE LONDON TRAMWAYS.

THE London Tramways were opened in 1871. The horsing was done by the Company themselves, except the horse power for the Brixton and Clapham lines, and for other services, which was supplied by the London General Omnibus Company until the middle of 1873, when the Tramway Company proceeded to horse the whole of the traffic themselves.

The amounts of capital expenditure are stated for the three years 1889—1891, as follows :—

CAPITAL EXPENDITURE, 1889—91.

Years.	Miles open at December 31.	Capital expenditure at December 31.	
		Total.	Per mile.
		£	£
1889	21⅝	593,364	27,448
1890	22¼	636,580	28,610
1891	22⅝	735,364	32,502

The details of the adjusted expenditure on capital account at December 31, 1891, are as follows :—

CAPITAL EXPENDITURE AT DECEMBER 31, 1891.

	£		Per mile. £
Tramways opened for traffic .	334,360	or	14,778
Property and buildings . .	208,378	,,	9,210
Rolling stock	54,200	,,	2,396

	£		Per mile. £
Horses and mules	117,334	or	5,185
Machinery and plant . .	16,130	,,	713
Harness and equipments . .	3,765	,,	166
Office furniture	644	,,	29
Advertising plant	551	,,	24
	735,362	,,	32,501

The stock of cars and omnibuses was as follows, showing that the one-horse cars were not increased in number, whilst the number of pair-horse cars was increased about 30 per cent. :—

CARS AND OMNIBUSES.

At	Pair-horse cars.	One-horse cars.	Omnibuses.	Total.
June, 1889 . .	201	24	29	254
Dec. ,, . .	206	24	29	259
June, 1890 . .	230	25	37	292
Dec. ,, . .	233	25	37	295
June, 1891 . .	238	25	38	301
Dec. ,, . .	258	25	37	320

HORSES AND MULES.

At	Horses and mules.	Added during half-year.	Sold.	Unfit for work.
June, 1889 . .	2,706	307	195	42
Dec. ,, . .	2,840	351	217	73
June, 1890 . .	3,211	611	240	98
Dec. ,, . .	3,226	301	286	132
June, 1891 . .	3,287	312	251	84
Dec. ,, . .	3,451	392	228	71
Average . .	3,120	379	236	82

On the basis of a stock of 2,706 horses and mules in June, 1889, as explained in the preceding chapter, it appears that 236 per half-year, or 472 per year, were sold and renewed out of "additions," and the average life thus indicated was (2,706 ÷ 472 =) 5·7 years.

The miles run by cars, the receipts, and the numbers of passengers, are subjoined :—

MILES RUN, RECEIPTS, AND PASSENGERS, 1889—91.

Year.	Miles run by cars.	Receipts from traffic.	Sundry Receipts.	Total receipts.	Per cent. of capital expended.
		£	£	£	per cent.
1889	6,468,224	280,418	3,036	283,454	48·9
1890	7,248,591	312,098	4,364	316,462	51·4
1891	7,755,898	312,767	4,819	317,586	48·6

Year.	Average length of way open.	Receipts per average mile open.	Per mile per week.	Per car.	Per mile run.
	Miles.	£	£	£	d.
1889	$20\frac{5}{8}$	13,743	264·3	1,105	10·36
1890	$21\frac{15}{16}$	14,415	277·2	1,078	10·45
1891	$22\frac{7}{16}$	14,154	272·2	1,023	9·77
1891	Receipts per car on duty (average 303) = £1,032.				

Year.	Number of passengers.			Receipts from passengers.	
	Total.	Per car.	Per mile run.	Total.	Per passenger.
				£	£
1889	57,787,921	225,294	8·96	280,418	1·16
1890	62,584,016	213,232	8·48	312,098	1·19
1891	63,588,485	204,793	8·16	312,767	1·19
1891	Number of passengers per car running (av. 303) = 209,863 Do. per car per day of 365 = 575				

The working expenditure for the three years 1889-91, here annexed, is given according to the classification of accounts followed by the tramway company. The statement is here followed by abstracts of the horsing expenses and the traffic expenses. The wages of drivers and pole-shifters are charged as traffic expenses, not running expenses, as is done by the North Metropolitan Company.

WORKING EXPENDITURE, 1889—91.

Items.	1889.	1890.	1891.	1891. Proportional parts of total expenditure.	1891. Expenditure per mile run.
	£	£	£	per cent.	Pence.
Horsing expenses . .	103,222	116,037	133,058	50·39	4·09
Traffic expenses . .	71,264	80,791	90,929	34·76	2·09
General expenses . .	7,861	6,096	7,116	2·66	·24
Rates on way . .	1,681	2,057	2,044	·78	·07
Repairs and renewals .	30,949	30,283	29,438	10·99	·96
Income tax . . .	1,656	1,626	1,658	·42	·05
Totals . . .	216,633	236,890	264,243	100·00	7·44
Do. per mile open .	10,503	10,796	11,804	—	—
Do. per mile run . .	8·02*d.*	7·83*d.*	8·07*d.*	—	—
Do. per cent. of receipts	70%	74%	82%	—	—

HORSING EXPENSES, HALF-YEAR, DECEMBER, 1891.

				s.	d.	£
Maize . . .	10,058½	quarters	@	29	3	14,711
Oats .	8,966	,,	@	21	10¾	9,810
Beans . .	72	,,	@	35	3¾	127
Peas . .	919	,,	@	34	0½	1,565
Lentils . .	1,533¼	,,	@	29	2	2,239
Bran . .	3,507¾	cwts.	@	5	3¾	927
Hay and clover .	3,635¼	loads	@	63	5¾	11,538
Straw . .	393½	,,	@	32	5¾	639
	Carried forward . .					£41,556

		£		Per mile run.
	Brought forward . .	41,556		
Sawdust . .	48,851 sacks @ 10¼d.	2,164		
Sundries		409		
		44,129	=	2·57d.
Granary wages		1,187	=	·06
Horsekeeper's wages		13,708	=	·80
Shoeing		2,758	=	·17
Veterinary attendance		491	=	·02
Rent, rates and taxes of stables. . .		2,305	=	·16
Rent, rates and taxes of granary . .		250	=	·01
Repairs to stables		127	=	·01
Sundry stable expenses		434	=	·02
Horse renewal		4,456	=	·25
		69,845	=	4.07
Less manure		139	=	·01
		69,706	=	4·06

HORSING EXPENSES PER HORSE PER WEEK, HALF-YEAR DECEMBER, 1891.

Per horse.	Half-year ending Dec. 31, 1891.			Per week.	
	£	s.	d.	s.	d.
Provender	12	15	7	9	10
Granary wages	0	6	6	0	3
Horsekeeper's wages	3	19	6	3	0¼
Shoeing	0	15	11	0	7½
Veterinary attendance	0	2	10	0	1¼
Rent, rates, and taxes of stables .	0	13	4	0	6
Rent, rates and taxes of granary .	0	1	5	0	0½
Repairs to stables	0	0	7	0	0¼
Sundry stable expenses	0	2	6	0	1¼
Horse renewal	1	5	10	1	2
Total	20	4	0	15	8
Less manure	0	0	9½	0	0½
	20	3	2½	15	7½

TRAFFIC EXPENSES, HALF-YEAR DECEMBER, 1891.

	£		Per mile run. pence.
Drivers' and conductors' wages	34,533	or	2·04
Pole-turners and pointsmen	794	,,	·04
Traffic superintendence	575	,,	·03
Timekeepers' wages	429	,,	·02
Rents, rates and taxes of car-sheds, workshops, and offices	2,193	,,	·13
Car lighting and oiling	275	,,	·01
Car washing	1,975	,,	·12
Track cleaning	696	,,	·04
Tickets	607	,,	·03
Traffic, stationery, printing, waybills, &c.	284	,,	·01
Traffic manager, cashiers, clerks, punch foremen, cash collectors, &c.	2,060	,,	·12
Ticket check	719	,,	·04
Salt and sand	705	,,	·04
Punch royalty	500	,,	·03
Police licenses and excise	496	,,	·02
Compensation	1,497	,,	·08
	48,338	,,	2·82

REPAIRS AND RENEWALS, 1889—91.

	1889.	1890.	1891.
	£	£	£
Permanent way	12,000	12,000	12,000
Rolling stock	9,268	7,684	6,451
Leases renewal fund	2,750	3,000	3,000
Property and buildings	2,409	2,201	1,852
Machinery, 20°/₀ per annum on expenditure	2,330	2,909	3,539
Harness and equipments, 50°/₀ on expenditure	2,018	2,292	2,402
Office furniture, 10°/₀ on expenditure	67	65	68
Advertising plant, 20°/₀ on expenditure	109	131	124
Total	30,951	30,282	29,436
	Pence	Pence	Pence
Do. per mile run	1·14	1·00	·95

MAINTENANCE OF WAY, 1889—91.

Year.	Average length open.	Cost for maintenance of way.			
		Amount.	Per mile of way.	Per square yard of way.*	Per mile run by cars.
	Miles.	£	£	Pence.	Pence.
1889	$20\frac{5}{8}$	5,769	279	6·99	·22
1890	$21\frac{15}{16}$	9,402	428	10·15	·31
1891	$22\frac{7}{16}$	15,296	682	16·36	·48

* Allowing 10,000 square yards per lineal mile.

MILEAGE RUN AND REPAIR OF CARS, 1889—91.

Year.	Average number of cars.	Miles run by cars.			Cost for repairs.		
		Number.	Per car.	Per car per day of 365.	Amount.	Per car.	Per mile run.
					£	£	Pence.
1889	$256\frac{1}{2}$	6,468,224	25,217	69·07	9,267	36·12	·34
1890	$293\frac{1}{2}$	7,248,591	24 699	67·66	7,683	26·14	·25
1891	$310\frac{1}{2}$	7,855,898	25,300	69·31	6,451	20·76	·19
Average . .			25,072	68·68	—	27·67	·26

The Bill lodged by the Company for the right to employ mechanical power by cable traction on the line between Kennington Cross and Telford Avenue, received Royal Assent in 1890. The line has recently (March, 1893), been opened for traffic.

CHAPTER IV.

CAPITAL, RECEIPTS, AND WORKING EXPENDITURE OF THE LONDON STREET TRAMWAYS.

THESE tramways were first opened in December, 1871, with 4½ miles of way. The length of way open at December 31, 1891, was 13¼ miles.

The horsing power was hired from the London General Omnibus Company, from the time of opening until April, 1875, when the Tramway Company acquired their own horses and worked the line themselves.

The total capital expenditure at the end of the three years, 1889—91, was as follows (for a length of 13¼ miles—about £40,000 per mile) :—

CAPITAL EXPENDITURE, 1889—91.

Year.	Miles open at Dec. 31.	Lands, buildings, way, &c.	Rolling stock.	Machinery, harness, &c.	Horses.	Total.	Total per mile open.
		£	£	£	£	£	£
1889	13¼	362,168	24,681	2,837	39,535	429,221	39,928
1890	13¼	364,748	25,539	2,627	40,561	433,475	40,323
1891	13¼	364,966	25,882	2,380	42,248	435,476	40,509

It is notable that the capital expended per mile, on the three

London companies just dealt with, vary in amount in some proportion inversely as the total lengths of way, thus:—

	Length of way.	Cost per mile.
North Metropolitan . .	49 miles	£31,388
London	22⅝ ,,	32,501
London Street . . .	13¼ ,,	40,509

MILES RUN, RECEIPTS, PASSENGERS, IN THE THREE YEARS 1889—91.

Year.	Miles run by cars.	Receipts from traffic.	Sundry receipts.	Total receipts.	Per cent. of capital.
		£	£	£	
1889	2,392,027	119,498	1,031	120,529	28
1890	2,454,354	127,705	1,442	129,147	30
1891	2,492,929	130,624	1,522	132,146	30½

Year.	Average length of way open.	Receipts per average mile open.	Receipts per mile open per week.	Receipts per car.	Receipts per mile run.
	Miles.	£	£	£	Pence.
1889	13¼	9,096	174·9	1,138	12·09
1890	13¼	9,767	187·8	1,171	12·65
1801	13¼	9,973	191·8	1,146	12·72

Year.	Number of passengers.			Receipts from passengers.	
	Total.	Per car.	Per mile run.	Total.	Per passenger.
				£	Pence.
1889	22,720,062	216,381	9·4	119,498	1·26
1890	24,507,126	224,836	9·9	127,705	1·25
1891	24,310,829	213,253	9·7	130,624	1·28

WORKING EXPENDITURE 1889—91.

Items of Expenditure.	1889.	1890.	1891.		
			Total.	Per cent. of total expenditure.	Per mile run.
DIRECT EXPENDITURE.	£	£	£	%	Pence.
Horsing . . .	43,628	45,090	50,025	44·93	5·02
Wages of drivers and pole-shifters .	12,025	12,845	13,152	11·82	1·33
Repairs of cars .	3,589	3,829	3,747	3·37	·38
,, of buildings	566	568	600	·54	·06
Maintenance of way	6,175	7,282	7,607	6·90	·77
Traffic . . .	16,981	18,311	20,347	18·28	2·04
General charges .	6,219	6,311	6,271	5·63	·63
Rent, rates, and taxes (on buildings)	2,225	2,578	2,760	2·48	·26
Total direct . .	96,408	97,334	104,589	93·95	10·49
CONTINGENT EXPENDITURE.					
Income tax and rates (on permanent way) gas and water .	3,900	3,943	4,651	4·18	·44
Licenses and excise duties . . .	413	359	349	·31	·03
Compensation . .	1,143	1,220	884	·80	·08
Legal and parliamentary . .	819	710	846	·76	·08
Total contingent .	6,275	6,232	6,730	6·05	·65
TOTAL EXPENDITURE .	102,683	103,566	111,319	100·00	11·14
Per mile open . .	9,552	9,634	10,355	. .	. .
	d.	*d.*	*d.*	. .	. .
Per mile run . .	10·25	10·12	10·68	. .	. .
Per cent. of receipts	85%	80%	84%	. .	. .

HORSES AT THE ENDS OF THE LAST SIX HALF-YEARS TO DECEMBER 31, 1891.

End of half-year.	Number of horses.	Sold and died.	Added.
June, 1889	1,110	55	120
Dec., ,,	1,104	67	61
June, 1890	1,143	85	124
Dec., ,,	1,132	68	57
June, 1891	1,159	62	89
Dec., ,,	1,177	75	93
Averages	1,137	69	91

RUNNING EXPENSES HALF-YEAR DECEMBER, 1891.

	Qrs.		s.	d.	£		Per mile run. d.
Maize	4,425	@	27	11	6,171		
Oats	4,302	@	18	7	3,991		
Beans	150	@	33	6	251		
Peas	307	@	32	9	503		
	Loads.						
Hay	1,293	@	65	6	4,235		
Straw	62	@	33	11	105		
	Cwts.						
Bran	196	@	5	11½	58		
Moss litter					489		
Tares, oatmeal, and sundries					246		
Barging and cartage					473		
					16,522		
Less manure					95		
					16,427	=	3·16
Stable foremen, horsekeepers, leader boys, watchmen, and general wages					5,078	=	·96
Granary wages and expenses					521	=	·09
Miscellaneous stable expenses					39	=	·01
Repairs to machinery					42	=	·01
Veterinary service					145	=	·03
Repairs to harness					574	=	·09
Shoeing					998	=	·18
Horse renewals					2,410	=	·43
					26,234	=	4·96

HORSING EXPENSES PER HORSE PER WEEK IN HALF-YEAR, DECEMBER, 1891.

Per horse.	Half-year ending Dec. 31st, 1891.			Per week.	
	£	s.	d.	s.	d.
Provender	14	0	1	10	9¼
Stable foremen, horsekeepers, leader boys, watchmen, and general wages	4	6	7	3	4
Granary wages and expenses	0	8	11	0	4
Miscellaneous stable expenses	0	0	8	0	¼
Repairs to machinery	0	0	9	0	¼
Veterinary service	0	2	6	0	1
Repairs to harness	0	9	11	0	4½
Shoeing	0	17	0	0	8
Horse renewals	2	1	1	0	7
Total actual cost	22	7	6	16	2¼

MILEAGE RUN AND REPAIRS OF CARS, 1889—91.

Year.	Average number of cars.	Miles run by cars.			Cost for repairs.		
		Total.	Per car.		Total	Per car.	Per mile run.
			Total.	Per day of 365.			
	Cars.	Miles.	Miles.	Miles.	£	£	Pence.
1889	105	2,392,027	22,781	62·13	3,589	33·13	·35
1890	109	2,454,354	22,517	61·67	3,829	35·12	·37
1891	114	2,492,929	21,868	59·88	3,748	32·87	·36
Averages			22,392	61·23	—	33·71	·36

MAINTENANCE AND RENEWAL OF WAY, 1889—1891.

Year.	Average length open.	Cost for maintenance of way.			
		Total.	Per mile of way.	Per square yard of way.*	Per mile run by cars.
	Miles.	£	£	Pence.	Pence.
1889	13¼	6,175	551	13·2	·62
1890	13¼	7,282	677	16·2	·71
1891	13¼	7,687	713	17·1	·74

* Allowing 10,000 square yards per lineal mile.

The tramways in the Caledonian Road were reconstructed with steel girder rails in 1889—90.

CHAPTER V.

CAPITAL, RECEIPTS, AND WORKING EXPENDITURE OF THE SOUTH LONDON TRAMWAYS.

THE through routes of these tramways were opened in the course of 1884. The subjoined statistics relate to the years 1889 to 1891:—

CAPITAL EXPENDITURE, 1889—1891.

Year.	Miles open at Dec. 31.	Lands, buildings, way, &c.	Rolling stock.	Preliminary and Parliamentary expenses.	Machinery and plant.	Harness and equipments.	Office furniture.	Advertising plant.	Horses.	Total.	Total per mile open.
		£	£	£	£	£	£	£	£	£	£
1889	$12\frac{9}{10}$	303,979	14,280	20,188	1,856	965	100	188	22,195	363,751	22,198
1890	$12\frac{9}{10}$	308,363	13,860	20,188	1,812	948	108	150	21,793	367,222	28,467
1891	$12\frac{9}{10}$	328,667	14,280	—	1,793	1,110	100	96	21,160	367,206	28,466

ROLLING STOCK AND HORSES, 1889—1891.

	1889.	1890.	1891.
Cars	86	86	86
Omnibuses	16	13	16
	102	99	102
Horses . . .	772	758	736

HORSES AT THE ENDS OF THE LAST SIX HALF-YEARS TO DECEMBER 31, 1891.

	Total number.	Added.	Sold and died.	Sick.	Lame.
June, 1889 .	764	73	69	1	13
Dec., ,, .	772	60	52	5	20
June, 1890 .	785	72	59	7	13
Dec., ,, .	758	49	76	2	19
June, 1891 .	788	132	102	6	34
Dec., ,, .	736	48	100	4	28
Averages . .	767	72	76	4	21

MILES RUN, RECEIPTS, PASSENGERS, IN THE THREE YEARS 1889—1891.

Year.	Miles run.	Receipts from traffic.	Sundry receipts.	Total receipts.	Per cent. of capital.
		£	£	£	
1889	1,738,333	71,132	819	71,951	19·78 %
1890	1,757,885	73,822	999	74,821	20·37 %
1891	1,746,074	75,490	1,178	76,668	20·88 %

Year.	Average length of way open.	Receipts per average mile open.	Receipts per mile per week.	Receipts per car and omnibus.	Receipts per mile run.
	Miles.	£	£	£	Pence.
1889	12$\frac{9}{10}$	5,677	109	705	9·93
1890	12$\frac{9}{10}$	5,800	111·5	756	10·23
1891	12$\frac{9}{10}$	5,943	114·3	751	10·54

Year.	Number of passengers.				Receipts from passengers.	
	Total.	Per vehicle.	Per vehicle per day of 365.	Per mile run.	Total.	Per passenger.
					£	Pence.
1889	15,671,679	153,644	421	9·01	71,951	1·10
1890	16,314,910	166,817	457	9·26	74,821	1·10
1891	16,666,858	163,302	447	9·54	76,668	1·11

The mileage-run and earnings in 1889 are given separately for main-line cars, cross-line cars and omnibuses, and one-horse cars, as shown in the following tablet:—

Miles run, and Earnings by Cars and Omnibuses separately, 1889.

Vehicles.	Miles run.	Earnings.	Per mile run.
		£	Pence.
Main-line cars	1,248,691	53,348	10·24
Cross-line cars and omnibuses .	394,599	15,945	9·70
One-horse cars	95,043	1,839	4·64
Total	1,738,333	71,132	10·16

Reduced to pair-horse mileage by calculating every two miles run by a one-horse vehicle as being equal to one mile run by a pair-horse vehicle.

Total	1,690,812	71,132	10·41

Working Expenditure, 1889–1891.

Items.	1889.	1890.	1891.	1891. Proportional parts of total expenditure.	1891. Expenditure per mile run.
	£	£	£	Per cent.	Pence.
Horsing expenses .	29,715	30,020	36,619	50·91	5·05
Traffic expenses . .	21,324	23,649	24,028	33·40	3·25
General expenditure .	1,644	2,217	1,702	2·36	·24
Rates on permanent way	12	11	10	—	. .
Repairs and renewals .	10,268	11,383	9,542	13·33	1·32
Total expenditure .	62,963	67,280	71,901	100·00	9·86
Do. per mile open .	4,881	5,215	5,573	—	—
	Pence.	Pence.	Pence.		
Do. per mile run . .	8·86	9·23	9·86	—	—
Do. per cent. of receipts	88·4 %	90 %	92·4 %	—	—

HORSING EXPENSES, HALF-YEAR, DECEMBER, 1891.

	Qrs.	Bushls.		s.	d.	£		
Maize	2,427	5	@	30	9	3,733		
Oats	3,467	0	@	20	11	3,629		
Beans	27	7	@	38	0	53		
	Loads.	Tr.						
Clover	249	13	@	64	10	809		
	Cwts.	Qrs.						
Bran	550	2	@	6	0	166		
	Qrs.	Bus.						
Peas	100	0	@	36	6	183		
	Cwts.	Qrs.						
Oatmeal	34	2	@	14	8	25		
	Lds.	Trs.						
Hay	488	33	@	57	5	1,405		
Straw	241	6	@	32	0	385		
	Tons.	Cwt.						
Moss Litter	219	5	@	24	6	269		
Sundries						70		
								Per mile run.
						10,736	=	2·94*d.*
Granary wages						296	=	·08
Horsekeepers' wages						2,869	=	·81
Shoeing						711	=	·18
Veterinary attendance						150	=	·04
Rent, rates and taxes of stables						690	=	·18
Rent, rates and taxes of granary						46	=	·01
Sundry stable expenses						125	=	·03
Horse renewal						3,061	=	·89
						18,674	=	5·16

HORSING EXPENSES PER HORSE PER WEEK IN HALF-YEAR, DECEMBER, 1891.

Per horse.	Half-year ending Dec. 31, 1891.			Per week.	
	£	s	d.	s.	d.
Provender	13	18	10	10	9
Granary wages	0	7	9	0	3½
Horsekeeper's wages	3	14	9	2	9½
Shoeing	0	18	5	0	8½
Veterinary attendance	0	3	10	0	1¾
Rent, rates and taxes of stables	0	17	11	0	8¼
Rent, rates and taxes of granary	0	1	2	0	0½
Sundry stable expenses	0	3	3	0	1½
Horse renewal	3	19	4	3	0½
Total actual cost	24	5	3	18	7

REPAIRS AND RENEWALS, HALF-YEAR, DECEMBER, 1891.

	£		Per mile run. Pence.
Permanent way	2,000	=	·52
Rolling stock	1,476	=	·40
Leases renewal fund	300	=	·06
Property and buildings	524	=	·14
Machinery	95	=	·02
Harness and equipments	409	=	·08
Advertising plant	24	=	·01
	4,828	=	1·23

MILES RUN, AND REPAIRS OF CARS, 1889—1891.

Year.	Average number of vehicles.	Miles run.			Cost for repairs.		
		Total.	Per vehicle.		Total.	Per car.	Per mile run.
			Total.	Per day of 365.			
		Miles.	Miles.	Miles.	£	£	d.
1889	101½	1,738,333	17,126	46·9	10,268	101·1	1·40
1890	99	1,757,885	17,758	48·6	11,383	115	1·51
1891	102	1,746,074	17,118	46·8	9,542	93·5	1·32

MAINTENANCE OF WAY, 1889—1891.

Year.	Average length open.	Cost for maintenance of way.			
		Amount.	Per mile of way.	Per sq. yard of way.*	Per mile run by cars.
	Miles.	£	£	Pence.	Pence.
1889	12·9	4,000	310	7·44	·55
1890	12·9	5,600	434	10·41	·78
1891	12·9	4,000	310	7·44	·54

* Allowing 10,000 square yards per lineal mile.

The original Meakins way continues in use; but the Barker way has been nearly all replaced by steel girder rails.

CHAPTER VI.

CAPITAL, RECEIPTS, AND WORKING EXPENDITURE OF THE BIRMINGHAM CENTRAL TRAMWAYS COMPANY.

THE operations of this Company are conducted on the four systems of haulage:—by direct steam power, horse power, cable power, and electric power; and they afford an opportunity of directly comparing the motive powers.

The Bristol Road line was reconstructed and adapted in 1890 for electric haulage.

STEAM DEPARTMENT.

MILES RUN, RECEIPTS, PASSENGERS, IN THE TWO YEARS 1890, 1891.

Year.	Miles run by cars.	Receipts from traffic.	Sundry receipts.	Total receipts.	Receipts per mile run.
		£	£	£	Pence.
1890	1,169,883	73,760	824	74,584	15·38
1891	1,184,401	76,454	884	77,338	15·64

Year.	Number of passengers.		Receipts from passengers.	
	Total.	Per mile run.	Total.	Per passenger.
			£	Pence.
1890	13,797,864	11·80	73,760	1·26
1891	14,242,827	12·01	76,454	1·28

The working expenditure for the two years 1890 and 1891 is given in the following table. The percentages of the several expenses in parts of the whole expenditure in 1891 are given in the second last column.

WORKING EXPENDITURE FOR THE TWO YEARS 1890, 1891.

Item.	1890.	Per mile run.	1891.		
			Total.	Per cent. of total expenditure.	Per mile run.
	£	Pence.	£	Per cent.	Pence.
Engines . .	27,319	5·60	31,464	58·03	6·38
Car repairs .	1,744	·36	1,611	2·97	·33
Traffic expenses .	7,694	1·58	8,294	15·29	1·68
Permanent way and buildings .	6,402	1·31	7,640	14·10	1·55
General charges .	4,926	1·01	5,209	9·61	1·05
Total expenditure	48.085	9·86	54.218	100·00	10·99
Do. per cent. of receipts . .	64 %	—	70 %	—	—

The engine power, it is shown, monopolises nearly one-half of the whole working expenditure. The expenditure on engine power is given in detail in the following tablet :—

DETAILS OF THE WORKING EXPENDITURE FOR ENGINE POWER FOR 1890, 1891.

	1890.		1891.	
	Total.	Per mile run.	Total.	Per mile run.
	£	Pence.	£	Pence.
Wages . .	9,925	2·04	10,191	2·06
Fuel . . .	7,428	1·52	9.357	1·90
Water and gas .	1,093	·22	1,069	·22
Stores . . .	1,406	·29	1,721	·35
Sundries . .	392	·08	340	·07
Repairs . .	7,074	1·45	8.786	1·78
Total . .	27.318	5·60	31,464	6·38

HORSE DEPARTMENT.

MILES RUN, RECEIPTS, PASSENGERS, IN THE TWO YEARS 1890, 1891.

Year.	Miles run.		Omnibuses.		Tramways.		Sundry receipts.	
	By cars.	By omnibuses.	Receipts from traffic.	Receipts per mile run.	Receipts from traffic.	Receipts per mile run.	Total	Do. per mile run.
			£	Pence.	£	Pence.	£	Pence.
1890	131,931	664,660	27,380	9·94	5,222	9·46	827	·24
1891	131.528	506,196	23,507	11·13	5,049	9·24	721	·25

Year.	Total number of passengers.		Passengers per mile run.		Receipts from passengers.			
					Omnibuses.		Trams.	
	Cars.	Omnibuses.	Cars.	Omnibuses.	Total.	Per mile run.	Total.	Per mile run.
					£	Pence.	£	Pence.
1890	1,068,861	3,054,266	8·1	4·6	27,380	9·8	5,222	9·5
1891	1,114,388	2,638,028	8·5	5·1	23,507	11·1	5.049	9·2

WORKING EXPENDITURE FOR THE YEARS 1890, 1891.

	1890.	Per mile run.	1891.		
			Total.	Per cent. of total expenditure.	Per mile run.
	£	Pence.	£	Per cent.	Pence.
Horses, including Forage and wages	21,398	6·45	19,461	74·86	7·33
Vehicle repairs .	1,281	·39	1,426	5·48	·54
Traffic expenses .	3,944	1·19	3,360	12·93	1·26
Way and buildings . . .	304	·09	362	1·40	·14
General charges .	1,647	·49	1,392	5·33	·52
Total expenditure .	28,547	8·61	26,001	100·00	9·79
Do. per cent. of receipts . .	88 %	—	91 %	—	—

DETAILS OF THE WORKING EXPENDITURE FOR HORSE POWER IN 1890, 1891.

Item.	1890.		1891.	
	Total.	Per mile run.	Total.	Per mile run.
	£	Pence.	£	Pence.
Wages	7,211	2·17	6,479	2·44
Forage and bedding .	11,144	3·36	9,273	3·72
Veterinary and shoeing .	1,026	·31	1,052	·40
Water and gas . .	163	·05	166	·06
Harness repairs . .	402	·12	424	·16
Stable utensils . . .	141	·04	116	·04
Sundries	129	·04	199	·08
Renewals	1,181	·36	1,151	·43
Total . .	21,397	6·45	19,460	7·33

CABLE DEPARTMENT.

MILES RUN, RECEIPTS, PASSENGERS, IN THE TWO YEARS 1890, 1891.

Year.	Miles run.	Receipts from traffic.	Sundry receipts.	Total receipts.	Receipts per mile run.
		£	£	£	Pence.
1890	459,806	25,048	164	25,212	13·16
1891	522,876	27,781	180	27,961	13·51

Year.	Number of passengers.		Receipts from passengers.	
	Total.	Per mile run.	Total.	Per mile run.
			£	Pence.
1890	4,261,050	9·40	25,048	13·2
1891	5,241,362	10·01	27,781	12·7

WORKING EXPENDITURE IN THE TWO YEARS 1890. 1891.

Item.	1890.		1891.		
	Total.	Per mile run.	Total.	Per cent. of expend.	Per mile run.
	£	Pence.	£	Per cent.	Pence.
Haulage . . .	4,876	2·55	5,242	38·00	2·41
Cables and machinery	1,843	·96	2,078	15·07	·95
Car repairs . . .	747	·39	1,811	13·12	·83
Traffic expenses . .	2,349	1·22	2,820	20·45	1·30
Permanent way and buildings . . .	148	·08	279	2·02	·13
General charges . .	1,717	·90	1,565	11·34	·71
Total expenditure .	11,680	6·10	13,795	100·00	6·33
Do. per cent. of receipts	48 %	—	50 %	—	—

DETAILS OF THE WORKING EXPENDITURE FOR CABLE POWER IN 1890, 1891.

	1890.		1891.	
	Total.	Per mile run.	Total.	Per mile run.
	£	Pence.	£	Pence.
Wages . .	2,819	1·47	3,181	1·46
Fuel . . .	1,264	·66	1,446	·66
Stores . . .	574	·30	401	·19
Water and gas .	131	·07	152	·07
Sundries . .	89	·05	62	·03
Total . .	4,877	2·55	5,242	2·41

ELECTRIC DEPARTMENT.

MILES RUN, RECEIPTS, AND PASSENGERS FOR 1891.

Year.	Miles run by cars.	Receipts from traffic.	Sundry receipts.	Total receipts.	Receipts per mile run.
		£	£	£	Pence.
1891	138,396	8,657	76	8,733	15·18

Year.	Number of passengers.		Receipts from passengers.	
	Total.	Per mile run.	Total.	Per passenger.
			£	Pence.
1891	1,144,718	8·54	8,657	1·81

WORKING EXPENDITURE FOR THE YEAR 1891.

Item.	1891.		
	Total.	Per cent. of total expenditure.	Per mile run.
	£	Per cent.	Pence.
Electric haulage . .	2,971	52·01	5·15
Machinery . . .	168	2·96	·29
Car repairs . . .	1,113	19·12	1·93
Traffic expenses . .	772	13·46	1·34
Permanent way and buildings . . .	78	1·73	·14
General Charges . .	609	10·72	1·05
Total expenditure .	5,711	100·00	9·90
Do. per cent. of receipts	65 %	—	—

DETAILS OF THE WORKING EXPENDITURE FOR ELECTRIC POWER, 1891.

Item.	1891.	
	Total.	Per mile run.
	£	Pence.
Wages	1,502	2·60
Fuel	956	1·66
Stores	420	·73
Water and lighting . .	39	·07
Sundries	54	·09
Total . .	2,971	5·15

SUMMARY OF THE FOUR DEPARTMENTS.

MILES RUN, RECEIPTS, AND PASSENGERS, FOR TWO YEARS, 1890, 1891.

Year ending June 30.	Miles run.	Passengers carried.	Traffic receipts.	Sundry receipts.	Total receipts.
			£	£	£
1890	2,426,280	22,182,041	131,409	1,806	133,215
1891	2,483,397	24,381,323	141,448	1,860	143,308

Year.	Length open.	Receipts per mile open.	Per mile per week.
	Miles.	£	£
1890	24·79	5,373	103·3
1891	24·79	5,781	111·2

Year.	Number of passengers.		Receipts from passengers.	
	Total.	Per mile run.	Total.	Per passenger.
			£	Pence.
1890	22,182,041	9·1	133,215	1·39
1891	24,381,323	9·8	143,308	1.40

PASSENGERS, RECEIPTS, EXPENSES, IN 1890, 1891.

	Passengers carried.		Total receipts.		Working expenses.		Net profit.	
	1890.	1891.	1890.	1891.	1890.	1891.	1890.	1891.
			£	£	£	£	£	£
Steam .	13,797,864	14,242,827	74,583	77,338	48,084	54,219	26,499	23,119
Horse .	4,123,127	3,752,416	33,419	29,277	28,573	26,002	7,417	3,275
Cable .	4,261,050	5,241,362	25,212	27,961	11,681	13,975	11,417	14,166
Electric.	—	1,144,718	—	8,732	—	5,711	—	3,021

RECEIPTS, EXPENSES, AND PROFIT OR LOSS, PER MILE, 1890 TO 1893.

Year 1890—91 (June 30).	Miles run by cars and omnibuses (horse department).	Average receipts per mile run.	Expenses per mile run.	Net profit per mile run.
		Pence.	Pence.	Pence.
Steam . .	1,184,101	15·67	10·99	4·68
Horse . . .	637,724	11·02	9·79	1·23
Cable . . .	522,876	12·83	6·33	6·50
Electric . .	138,396	15·15	9·90	5·25
Averages . .	—	13·67	9·25	4·46

Year 1891—92 (June 30).	Miles run by cars and omnibuses (horse department).	Average receipts per mile run.	Expenses per mile run.	Net profit per mile run.
		Pence.	Pence.	Pence.
Steam . .	1,212,624	15·96	12·03	3·93
Horse . . .	634,551	11·20	9·96	1·24
Cable . . .	621,210	12·20	6·18	6·02
Electric . .	188,760	13·25	15·39	2·14 (loss)
Averages . .	—	13·15	10·89	2·26

Year 1892—93 (June 30).	Miles run by cars and omnibuses (horse department).	Average receipts per mile run.	Expenses per mile run.	Net profit per mile run.
		Pence.	Pence.	Pence.
Steam . . .	1,225,996	15·99	11·22	4·77
Horse . . .	647,652	10·93	10·12	·81
Cable . . .	641,161	12·69	6·32	6·37
Electric . .	140,993	16·38	16·55	·17 (loss)
Averages . .	—	13·99	11·05	2·94

CHAPTER VII.

CAPITAL, RECEIPTS, AND WORKING EXPENDITURE OF THE GLASGOW TRAMWAY AND OMNIBUS COMPANY.

AT December 31, 1880, the property of the Company stood at £348,224, including the value of 1,836 horses and mules, 178 cars, and 22 omnibuses. The length open for traffic was 19·89 miles. The miles run in the year 1880 were 2,785,562; the receipts were £155,074 from car traffic, £5,978 from omnibus traffic, and from sundry sources £6,339, amounting together to £167,400, or 14·47 pence per mile run. The expenditure, irrespective of reserves, depreciation, and Corporation charges, amounted to 62·4 per cent. of the receipts, or 9d. per mile run.

The actual working capital, after allowing for depreciation, was stated to be as follows at December 31, in the three years 1889—91.

ACTUAL WORKING CAPITAL EXPENDED, 1889—91.

	1889.	1890.	1891.
	£	£	£
Office furniture	335	300	250
Cars	(233) 29,960	(230) 23,000	(230) 17,250
Omnibuses	(30) 2,100	(30) 1,800	(24) 960
Horses and mules	(2768) 67,816	(2881) 65,783	(3149) 68,753
Plant, machinery, &c.	13,728	11,746	12,905
Harness, stable implements, &c.	5,783	5,205	4,018
Heritable property	181,229	172,167	167,347
Totals	£298,951	£280,001	£271,483

MILES RUN, RECEIPTS, AND PASSENGERS, 1889—1891.

Year.	Miles run.	Receipts from traffic.	Sundry receipts.	Total receipts.	Per mile run.	Per day of 365.
		£	£	£	Pence.	£
1889	4,388,019	227,663	8,772	236,435	12·93	648
1890	4,481,825	251,545	8,130	259,675	13·91	711
1891	not given	271,715	8,059	279,774	—	766

Year.	Average length open.		Receipts per average mile open.	Receipts per mile per week.
	Miles	chains	£	£
1889	30	17	7,866	151·4
1890	30	17	9,054	174·2
1891	30	17	9,260	178·1

Year.	Number of passengers.			Receipts from passengers.	
	Total.	Per day of 365.	Per mile run.	Total.	Per passenger.
				£	Pence.
1889	45,812,940	125,514	10·44	227,663	1·19
1890	50,237,996	137,665	11·20	251,545	1·20
1891	52,208,605	143,037	—	271,715	1·24

The receipts for the last half-year 1891 are here given in detail, as a sample :—

TRAFFIC RECEIPTS—		
Cars, omnibuses, cab and carriage hiring, and mails		£140,874
SUNDRY RECEIPTS—		
Manure	£1,322	
Parcels carriage to suburbs	301	
Advertising on cars, omnibuses, &c.	1,521	
Discounts and abatements	402	
Transfer fees	22	
Rents	565	
		4,133
Total		£145,007

The Sunday traffic for one year is given as follows :—

SUNDAY TRAFFIC.

	Half-year ending	
	December 31, 1888.	June 30, 1889.
Miles run on Sundays . .	123,815	119,345
Do. week days . .	2,353,520	2,053,244
Gross receipts on Sundays . .	£6,225 4s. 2d.	£6,245 11s. 10d.
Do. do. per mile run	12·068 pence.	12·056 pence.
Passengers carried on Sundays .	1,223,677	1,256,485

WORKING EXPENDITURE FOR THREE YEARS, 1889—1891.

	1889.	1890.	1891.	Proportional part of total expenses, 1891.
	£	£	£	Per cent.
Traffic expenses . .	123,389	131,759	149,696	64·98
General expenses .	16,635	15,579	14,457	6·33
Repairs and renewals .	27,304	30,973	35,136	15·76
Corporation charges .	30,193	30,048	29,608	12·93
Total expenditure .	£197,521	£208,359	£228,897	100·00

The form of the accounts does not give the means of determining the horsing and the traffic expenses separately. These are combined under one heading—Traffic Expenses—the details of which, with those of general expenses, repairs and renewals, are subjoined for the sample half-year ending December 31, 1891 :—

TRAFFIC EXPENSES FOR THE HALF-YEAR ENDING DECEMBER, 1891.

	£		Proportion of total. Per cent.
Provender and litter	41,204	=	50·33
Wages and maintenance, and interest for Ibrox line	33,874	=	41·38
Shoeing	2,604	=	3·18
Veterinary	97	=	·12
Lighting	274	=	·33
Ticket check	860	=	1·05
Police, licenses, and excise	185	=	·22
Washing and cleaning	884	=	1·11
Gas and water-rates	506	=	·61
Oil, waste, salt, and sand	255	=	·31
Uniforms	1,112	=	1·36
Total	£81,855	=	100·00

GENERAL EXPENDITURE FOR HALF-YEAR ENDING DECEMBER, 1891.

	£		Proportion of total. Per cent.
Salaries	1,238	=	17·43
Directors' fees	300	=	4·22
Audit fees	42	=	·58
Rents and feu duties	852	=	11·99
Rates and taxes	2,356	=	33·16
Compensation	460	=	6·47
Law costs	132	=	1·85
Insurance	843	=	11·86
Miscellaneous	168	=	2·36
Printing, stationery, &c.	187	=	2·63
Discount on tickets	237	=	3·33
Interest	293	=	4·12
Total	£7,108	=	100·00

COST FOR REPAIRS AND RENEWALS FOR HALF-YEAR ENDING DECEMBER, 1891.

	£	£		Proportion of total. Per cent.
Horses	7,595			
Amount written off to reduce the stock price to £21	2,624			
		10,219	=	58·93
Harness		1,420	=	8·18
Rolling stock		4,428	=	25·52
Machinery		502	=	2·92
Buildings		772	=	4·45
Total		£17,341	=	100·00

CORPORATION CHARGES FOR HALF-YEAR ENDING DECEMBER 31, 1891.

	£		Proportion of total. Per cent.
Interest on outlay, &c.	6,301	=	42·45
Sinking fund	3,429	=	23·11
Mileage rate	1,381	=	9·30
Renewal of tramways	3,728	=	25·14
Total	£14,839	=	100·00

The average cost for provender consumed by each stud of 10 horses for the years 1889—91, including straw and moss for litter (less amount received for manure), and wages of carters and others engaged in connection with the provender department, was as follows:—

HALF-YEAR.	£	s.	d.
June, 1889	99	8	0
December, 1889	106	10	8
June, 1890	98	14	6
December, 1890	104	11	1
June, 1891	108	19	11
December, 1891	127	15	7
Average for six months	107	13	7½
,, per horse, for six months	10	15	4¼
,, ,, for one year	21	10	8½

CHAPTER VIII.

CAPITAL, RECEIPTS, AND WORKING EXPENDITURE OF THE EDINBURGH STREET TRAMWAYS.

THE tramways of the city of Edinburgh have been constructed and worked under very considerable difficulties, municipal and physical. Laid upon long and severe gradients, these tramways are more difficult to work than any other tramway system in the United Kingdom. The horse-power was supplied by contract during the first few years, in the course of which the contractor raised his terms, insomuch that on one section the Company paid him the abnormal sum of tenpence per mile run—not unreasonable. For though the Company anticipated that not more than three horses would be required to work the system at any point, it was found that for working on the steepest gradients—on Leith Walk, North Bridge, and Portobello Road—four horses were required.

In 1874, the Company terminated the contract for horse power, acquired all the horses belonging to the contractor, and commenced to horse the lines themselves. The price paid for the horses, at a valuation, was only £28 per horse. The horses were not suited for the service, and it was not till the year 1876 that the horses thus acquired at a valuation were replaced by others suited to the work. On some of the gradients the labour is excessive, and the horses are very sorely tried. From the gradients in Leith Walk, averaging 1 in 32—of which the maximum gradient is 1 in 14—the horses are shifted every few months to another and easier section, on which there is no steeper gradient than 1 in 25. They begin to recover strength after having been worked for some time on the easier gradients, and they are again placed on the severer inclines. "But for such a rotation of duty, the horses," said Dr. Wood, the chairman of the Company, "would not last at all. As it was, they lasted a shorter time," he believed, "than in most other towns, and it was extremely difficult to keep them in condition."

The average cost for horse power in the year 1876, worked by the Company, amounted to 7¾d. per mile run by cars, which is probably the highest rate of cost in this country for tramway work. Naturally, the number of miles run per horse is less in Edinburgh than elsewhere. It amounts only to 5·80 miles per day of 313 in the year.

The miles run during the two years ending June 30, 1880, were 1,592,679 miles. The total receipts amounted to £123,669, or at the rate of £89 per mile per week, and 18·7 per mile run. The horsing expenses were at the rate of 8d. per mile run. The cost for maintenance of way and works amounted to £6,576, or to £245 per mile open per year, or about 1d. per mile run. But, for the last year alone, to June 30, 1880, the expenditure on the way amounted to £4,101, or £307 per mile, or 1·22d. per mile run. This excessive expenditure was incurred in renewing the way in Princes Street, Leith Street, Catherine Street, Leith Walk, and Great Junction Street, Leith, after having been open for eight or nine years.

Here follow particulars of capital, working expenditure, receipts, &c., for the three years 1889—1891 :—

CAPITAL EXPENDITURE FOR THREE YEARS 1889—1891.

Year.	Miles open at Dec. 31.	Preliminary, parliamentary, and Law expenses.	Land tramways and equipments.	Buildings, &c.	Cars, carriages, &c.	Omnibuses.	Horses	Total.	Total per mile open.
		£	£	£	£	£	£	£	£
1889	18¼	41,525	215,067	80,010	12,071	1,303	34,847	392,023	20,441
1890	18¾	41,525	215,067	84,722	13,330	1,113	38,270	394,747	21,080
1891	18¼	41,525	218,172	84,880	13,070	1,285	42,502	397,640	21,848

CARS, HORSES, ETC., AT DECEMBER 31, 1889—1891.

	1889.	1890.	1891.
Close cars	63	63	65
Canopy cars	..	8	10
Open cars	10	6	6
Omnibuses	10	8	9
Tourists coaches	4	4	4
Total rolling stock	87	89	94
Horses	895	981	958

MILES RUN, RECEIPTS, AND PASSENGERS, 1889—1891.

Year.	Miles run by cars.	Miles run by omnibuses and coaches.	Total miles run.	Receipts from traffic.	Sundry receipts.	Total receipts.	Per cent. of capital.
				£	£	£	Percent.
1889	1,396,904	86,739	1,483,643	96,316	5,656	101,972	26·02
1890	1,661,656	60,073	1,721,729	113,708	5,265	118,973	30·12
1891	1,603,497	64,950	1,668,447	103,017	4,808	107,825	27·13

Year.	Average length of way open.	Receipts per average mile open.	Receipts per mile per week.	Receipts per mile run.
	Miles.	£	£	Pence.
1889	18⅕	5,603	107·7	16·4
1890	18⅕	6,537	125·7	16·5
1891	18⅕	5,935	114·1	15·5

Year.	Number of passengers.						Receipts from passengers.	
	With cars.	With omnibuses.	With coaches.	With workmen's cars	Total.	Per mile run.	Total.	Per passenger
							£	d.
1889	13,603,441	166,419	247,435	180,490	14,197,735	9·57	96,316	1·62
1890	16,307,488	36,297	264,525	120,372	16,728,682	9·74	113,708	1·63
1891	15,081,704	322,606			15,404,310	9·75	103,017	1·61

WORKING EXPENDITURE, 1889—1891.

Item.	1889.	1890.	1891.	1891. Proportional parts of total expenditure.	1891. Expenditure per total mile run.
	£	£	£	Per cent.	Pence.
Working expenses .	15,160	20,275	19,108	24·09	2·74
Horsing expenses .	37,957	42,120	42,892	54·25	6·16
Car, omnibus and carriage repairs, and renewals .	3,797	4,572	3,989	5·01	·56
Maintenance of way	4,869	4,673	4,597	5·74	·66
General charges .	7,148	8,237	8,697	10·91	1·24
Total expenditure .	68,931	79,877	79 283	100·00	11·36
Total expenditure per mile open .	3,788	4,388	4,356	..	..
Do. per total mile run	Pence. 11·14	Pence. 11·13	Pence. 11·36	..	..
Do. per cent. of receipts	67·55	67·14	74·48	..	..

The "working" expenses include the wages of drivers and trace-boys or pole-shifters. The horsing expenses are, of course, by so much reduced, and they cannot be directly compared with the earlier costs for horsing.

HORSING EXPENSES FOR HALF-YEAR ENDING DECEMBER, 1891.

	£		Per total mile run. Pence.
Provender and litter	14,222	=	4·03
Stable wages and expenses	3,650	=	1·03
Harness	295	=	·08
Horse-shoeing	980	=	·28
Stable and machinery repairs	220	=	·07
Renewal of horses	2,229	=	·63
Total	21,602	=	6·12

HORSING EXPENSES PER HORSE PER WEEK FOR HALF-YEAR ENDING DECEMBER, 1891.

Per horse.	Per horse.			Per horse per week.	
	£	s.	d.	s.	d.
Provender and litter	14	16	10	11	5
Stable wages and expenses	3	16	2	2	10
Harness	0	6	2	0	2½
Horse-shoeing	1	0	7	0	9½
Stable and machinery repairs	0	4	8	0	2
Renewal of horses	2	6	6	1	9
Total	22	10	11	17	4

HORSE RENEWALS IN 1889—91.

	In stock.	Added.	Renewed.
June, 1889	892	30	98
Dec., 1889	895	3	91
June, 1890	1032	137	..
Dec., 1890	981	.	58
June, 1891	950	..	79
Dec., 1891	958	8	91
Averages	951	30	69

MILEAGE RUN AND REPAIRS OF CARS, 1889—91.

Year.	Average number of		Miles run.						Cost for repairs of cars, omnibuses, and carriages.		
			By cars.		By omnibuses and coaches, &c.		Total.		Total.	Per vehicle.	Per total miles run.
	Cars.	Omnibuses, &c.	Total.	Per car.	Total.	Per vehicle.	Total for cars, &c.	Per day [illegible]			
			Miles.	Miles.	Miles.	Miles.	Miles.	Miles.	£	£	Pence
1889	72½	14¼	[illegible]	16,267	[illegible]	[illegible]	[illegible]	[illegible]	3,797	43·7	[illegible]
1890	76½	12¾	1,661,656	21,721	60,073	4,806	[illegible]	[illegible]	1,572	[illegible]	[illegible]
1891	80	12½	1,603,497	20,045	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

MAINTENANCE OF WAY, 1889—91.

Year.	Average length open.	Cost for maintenance of way.			
		Total.	Per mile of way.	Per sq. yard of way.*	Per mile run by cars.
	Miles.	£	£	Pence.	Pence.
1889	18⅕	4,869	267	6·42	·77
1890	18⅕	4.673	256	6·14	·65
1891	18⅙	4·597	264	6·33	·66

* Allowing 10,000 sq. yards for lineal mile.

CHAPTER IX.

CAPITAL, RECEIPTS, AND WORKING EXPENDITURE OF THE ABERDEEN DISTRICT TRAMWAYS.

CAPITAL EXPENDITURE, 1889—1891.

Year.	Length open.	Buildings.	Way.	Cars and Omnibuses.	Horses.	Harness carts, &c.	Total.	Per mile open.
	m. ch.	£	£	£	£	£	£	£
1889	9 4	8,335	39,201	2,670	3,024	383	53,613	5,924
1890	9 4	8,689	39,201	2,410	2,460	368	54,128	5,981
1891	9 4	9,043	39,285	2,660	3,700	430	55,118	6,090

NUMBER OF HORSES, 1889—1891.

June 30, 1889	165
Dec. 31, 1889	161
June 30, 1890	176
Dec. 31, 1890	173
June 30, 1891	184
Dec. 31, 1891	185

RECEIPTS AND PASSENGERS, 1889—1891.

Year.	Traffic receipts.	Sundry receipts.	Total receipts.	Per cent. of capital.
	£	£	£	Per cent.
1889	15,345	712	16,057	30·0
1890	16,637	722	17,359	32·1
1891	17,368	771	18,139	33·0

Year.	Length open.		Receipts per mile open.	Receipts per mile per week.
	Miles.	chains.	£	£
1889	9	4	1,774	68·23
1890	9	4	1,918	73·76
1891	9	4	2,004	77·07

Year.	Number of passengers.		Receipts from passengers.	
	Total.	Per day of 365.	Total.	Per passenger.
			£	Pence.
1889	3,023,932	8,284	15,345	1·21
1890	3,271,507	8,963	16,637	1·22
1891	3,430,449	9,396	17,368	1·22

WORKING EXPENDITURE, 1889—1891.

	1889.	1890.	1891.	
			Total.	Proportional part of total expenditure.
	£	£	£	Per cent.
Working expenses, including wages of conductors, drivers, &c.	3,432	3,511	3,777	28·74
Horsing expenses .	5,445	5,905	6,921	52·66
Repairs . . .	909	850	922	7·02
General expenses .	1,269	1,287	1,522	11·58
Total expenditure .	11,055	11,553	13,142	100·00
Do. per mile open.	1,211	1,276	1,452	—
Do. per cent. of receipts. . .	68·84	66·55	72·45	—

HORSING EXPENSES, HALF-YEAR ENDING DECEMBER 31, 1891.

Item.	Total.	Per horse per half-year.			Per horse per week.	
	£	£	s.	d.	s.	d.
Forage	2,903	15	13	10	12	1
Condiment	13	0	1	5	0	0¾
Coals	18	0	1	11	0	1
Stable furnishings	31	0	3	4	0	1½
Horse-shoeing	217	1	2	4	0	10½
Stable wages	567	3	1	3	2	4½
	3,749	21	0	1	15	7¼

REPAIRS, HALF-YEAR ENDING DECEMBER 31, 1891.

	£		Proportion of total. Per cent.
Repairs to harness	53	=	11·68
,, cars	244	=	53·74
,, buses	11	=	2·42
,, buildings	37	=	8·15
,, implements	9	=	1·98
,, permanent way	100	=	22·03
Total	454	=	100·00

MAINTENANCE OF WAY, 1889—91.

Year.	Length open.	Maintenance of way.		
		Total.	Per mile of way.	Per square yard of way.*
	Miles.	£	£	Pence.
1889	$9\frac{1}{20}$	188	20·7	·49
1890	$9\frac{1}{20}$	257	28·3	·68
1891	$9\frac{1}{20}$	238	26·2	·62

* Allowing 10,000 sq. yards per lineal mile.

CHAPTER X.

PROPERTY, RECEIPTS, AND WORKING EXPENDITURE OF THE BLACKPOOL ELECTRIC TRAMWAY.

PROPERTY BELONGING TO THE COMPANY, OCTOBER 31, 1891.

	£
Tram shed	2,566
Engines, generators, motors, &c.	3,343
Centre channel and electrical fittings	8,435
12 cars, turntable, and traverser	2,157
Miscellaneous capital expenses	641
Total	£17,142

MILES RUN, RECEIPTS, AND PASSENGERS, FOR YEARS 1890, 1891.

Year.	Miles run by cars.	Traffic receipts.	Adver-tising.	Interest.	Total receipts.
		£	£	£	£
1890	92,000	6,281	183	27	6,491
1891	98,000	7,038	203	—	7,241

Year.	Length open.	Receipts per mile open.	Receipts per mile per week.	Receipts per car.	Receipts per mile run.
	Miles.	£	£	£	Pence.
1890	2	3,245·5	62·4	649·1	16·38
1891	2	3,620·5	69·6	603·4	17·23

Year.	Number of passengers.				Receipts from passengers.	
	Total.	Per car.	Per car per day of 365.	Per mile run.	Total.	Per passenger.
					£	Pence.
1890	812,299	81,229	223	8·82	6,281	1·84
1891	933,652	77,804	212	9·52	7,038	1·81

Year.	Number of cars.	Miles run by cars.			
		Total.	Per day of 365.	Per car.	Per car per day of 365.
		Miles.	Miles.	Miles.	Miles.
1890	10	92,000	252	9,200	25·2
1891	12	98,000	268	8,166	22·3

WORKING EXPENDITURE, 1890, 1891.

Items.	1890.	1891.	1891.	
			Proportion of total.	Per mile run.
	£	£	Percent.	Pence.
Repairing centre channel (labour and materials)	126	145	3·47	·35
Electrical fittings (repairing armatures, &c.)	170	192	4·57	·48
Wheels for cars, chain, cast bosses and cog rims, &c.	147	135	3·22	·33
Plumbers' work at water connections, &c.	23	78	1·88	·19
Repairing roadway for Corporation, between rails and 18 ins. outside thereof	113	189	4·51	·47
Wages of drivers, conductors, checkers, engineers, stokers, &c.	1,778	1,331	34·14	3·28
Coal, coke, oil, cotton waste, &c. .	281	291	6·92	·71
General charges	1,994	1,830	41·29	4·44
Total expenditure	4,032	4,191	100·00	10·25
Do. per cent. of receipts . .	64·18	59·91	—	—
Do. per mile open	2,016	2,095	—	—
	Pence.	Pence.		
Do. per mile run	10·51	10·25	—	—

CHAPTER XI.

LONDON GENERAL OMNIBUS COMPANY.

THE management and experience of the London General Omnibus Company having been long-continued and successful, it will be well, in the first place, to epitomise some of the results of their experience, drawn from their half-yearly reports.

In 1875—76, a considerable proportion of the business of the Company consisted in supplying horse-power to the North Metropolitan Tramways Company. It is not possible, therefore, to deduce from the accounts the net cost for omnibus service. The following epitome contains all that can usefully be abstracted for comparison with the accounts of tramway companies:—

CAPITAL ACCOUNT, TRAFFIC, RECEIPTS AND EXPENDITURE, 1875, 1876.

	1875. £	1876. £
Capital in property, leases, and buildings	73,808	73,808
Stock-in-trade—omnibuses, horses, harness, goodwill, and appurtenances	522,116	521,540
Total	£595,924	£595,348
Omnibuses :—		
Miles run	11,619,606	11,806,956
Average number of omnibuses on daily duty on week days	564	568
Ditto on Sundays	460	470
Ditto for seven days a week	550	554
Miles run per omnibus on duty per year	21,130	21,320
Number of passengers carried by omnibuses	49,720,038	51,157,946
Ditto per mile run	4·28	4·33
Average number of horses	7,913	7,893

Receipts :—	1875. £	1876. £
Ordinary omnibus traffic and hire	537,905	544,056
Horsing tramway cars	106,194	100,573
Manure and advertising	9,447	9,012
Total Receipts	£653,546	£653,641
Receipts per cent. of capital in property at the end of the year	109·6 %	109·8 %
Receipts from omnibus traffic per omnibus on duty	£978	£982
Ditto per day (365)	£1,474	£1,491
Ditto per omnibus per day	£2 13s. 7d.	£2 13s. 6½d.
Ditto per mile run	11·11d.	11·05d.
Ditto per passenger	2·60d.	2·55d.

Average Working Expenditure for two years, 1875—76.

Miles run per year, 11,713,281.

Direct expenditure :—	Per year.	
Horsing, including renewal of horses (7,903 horses)	£404,618	
Ditto per horse	£51·2	
Maintenance of omnibuses and aprons	£29,431	
Ditto ditto per omnibus on duty, 552		£53·3
Ditto ditto per mile run		0·60d.
Traffic charges, including wages of drivers and conductors	£115,883	
General charges, including rents	£27,410	
Total	£577,342	

Contingent expenditure :—		Per mile run.
Rates and taxes	£2,776	
Excise duties and licenses	£2,586	
Compensation and law charges connected therewith	£3,620	or ·047d.
	£8,982	
Total expenditure	£586,324	

The numbers of new omnibuses that were constructed as renewals of omnibus stock in the course of two years was as follows:—

Half-year ending June, 1875	9
Ditto December, 1875	11
Ditto June, 1876	14
Ditto December, 1876	13
New omnibuses in two years	47

The mileage run by omnibuses during the same period amounted to 23,426,562 miles, equivalent to 498,440 miles per omnibus replaced. The life of an omnibus was therefore deducible, in round numbers, as 500,000 miles. Again, the average annual number of miles run per omnibus on daily duty was 21,225 miles. If it be taken at 21,000, a round number, the average life in years of the omnibuses, supposing that they were on duty every day continuously, would be twenty-four years. But, necessarily, they are off duty for repairs from time to time; and though the accounts did not show how many surplus omnibuses there were in stock, it may be assumed, for present purposes, that 80 per cent. of the whole number was on daily duty, and 20 per cent., or a fourth more, was in reserve and under repair. Adding, correspondingly, a fourth to the number of years above found, thirty years is arrived at as the actual life in time of an omnibus.

The length of the lives of the horses contrasts unpleasantly with the length of life of the omnibuses. The average total number of horses and the number of carcases and living horses sold when unfit for duty, during the years 1875-76, were as follows:—

Year.	Average total number of horses.	Number sold.	Per cent. of total.
1875	7,913	1,889	23·9 per cent.
1876	7,893	1,774	22·5 ,,
Averages .	7,903	1,832	23·2 ,,

showing that upwards of 23 per cent. of the stock of horses were old, and, of course, replaced per year. From these data it follows that the whole of the stock of horses was renewed in

$$\frac{100}{23\cdot2} = 4\cdot31 \text{ years;}$$

and that thus the life of an omnibus horse was 4·31 years; varying from 4·2 years in 1875 to 4·44 years in 1876.

Mr. A. G. Church, the late general manager and secretary of the Company, stated, on an extended basis of experience, that the life of a horse varied from four years to four and a half years in the service; four years on tramway service, and four and a half years on omnibus service. The shorter life of the tramway horse was easily accounted for by the greater effort required to start a tramway car, in consequence of the greater mass, rigidity, and weight, compared with the condition of an omnibus; together with the greater frequency of the stoppages to which the tramcar is subject, arising from the greater number of passengers carried by the car, and from the number of stoppages incurred in addition by the occasional blockage of the tramway by other vehicles. The frequently repeated efforts required of the horses to start the cars tell disastrously upon their condition ; for, although the resistance to a tramcar on a tramway is much less per ton than the resistance to an omnibus on a common road, yet the effort of traction required to start a tramcar is much greater than that for an omnibus. The greater frequency of the stoppages of the tramcar for passengers than of the omnibus was proved by the greater number of passengers per mile run by the car, which amounted to about 7½ passengers per mile run on the North Metropolitan Tramways—worked by the Omnibus Company—and to only 4·30 passengers per mile run by the omnibus. It is very probable, taking into account extra stoppages by the car and by the omnibus, that the former was stopped and started at least twice as frequently as the latter.

There is a significance in the correspondence between the number of horses sold and replaced, and the receipts from omnibus traffic and the horsing of tramway-cars in the two years 1875 and

1876. Thus, in 1876 the receipts from omnibus traffic were about £6,000 greater, and those from tramways were about the same amount less than in 1875. The easement was made apparent in the smaller number of horses sold in 1876: it was 1,774 as against 1,889 sold in the previous year.

The proportional number of carcases and living horses sold during the year ending June 30th, 1876, were:—

1,208 carcases	or 65	per cent.
676 living horses	or 35	,,
1,884 sold	100	,,

showing that two-thirds of the horses that were sold either died or were worn out in the service, and that a third were sold as only fit for agricultural work—too weak, or affected with bent knees. From the results of more extended data, Mr. Church stated that the proportion of carcases and living horses sold were about 60 per cent. and 40 per cent. The horses were purchased at about the age of five years for about £40 each, and they were sold when worn out for £9 or £10. For agricultural service they fetched on re-sale sometimes as much as £16, £17, or £18.

The horses were fed almost entirely with maize; oats as a staple of food had been abandoned. The following were the quantities and the costs of provender for the half-year ending December 31, 1876, including the cost of preparation, cartage, lighterage and expenses at the depôts:—

Quarters.		£	s.	d.	£	s.	d.
1,419 oats	@	1	3	9	1,685	18	5
49,179 maize	,,	1	8	2	69,317	13	6
921 beans	,,	2	8	7	2,237	7	9
3,197 bran	,,	0	11	1	1,769	19	7
Loads.							
4,399 hay and clover	,,	6	6	6	27,828	11	11
8,618 straw	,,	2	6	3	19,947	1	6
Sundry and grass farm					141	17	0
					122,928	9	8

The weight of the grain consumed was as follows:—

	Tons.	cwts.	qrs.	lbs.
Oats, 1,419 quarters	192	11	2	8
Maize, 49,179 "	10,538	7	0	16
Beans, 921 "	205	11	2	12
Total weight	10,936	10	1	8

The average cost for provender consumed by each stud, including the expenses in connection with the provender department, was £174.

It appears from the foregoing statements that the total cost for maintenance and renewal of horses was £51 4s. per year per horse, or about £1 per week.

The reports of the Omnibus Company for the past three or four years (writing in 1878) comment upon "the deplorable state of the main thoroughfares in the eastern, southern, and northern parts of the metropolis, which were destructive of the wheels, springs, and under-carriages of ordinary vehicles. The cost for wheels alone for the Company's omnibuses increased from £9 10s. per omnibus per year to £15 per year since the introduction of tramways. Valuable horses have constantly been injured by straining and slipping on the rails."

Coming now to the operations of the Company in more recent years—the two years ending June 30, 1890-91—the working capital expenditure was as follows:—

CAPITAL EXPENDITURE AT JUNE 30, 1891.

	£
Land, buildings, and leaseholds . . .	100,159
Omnibuses, horses, harness, &c. . . .	580,661
Gas and water fittings	3,908
Stable fittings and stores	6,553
Office furniture and fixtures	1,016
Total	£692,297

On June 30, 1891, there were 9,796 horses; the average price paid during the half-year was £35 1s. 10d. per horse; 797 carcases and 440 living horses were sold.

The gross receipts in the half-year, with other particulars, were as follows:—

	£
Ordinary omnibus traffic and private hire	318,295
Advertising in and upon omnibuses	7,290
Manure	1,194
Total	326,779

	1891.
The number of passengers carried by omnibuses was	53,843,477
The average number of omnibuses working on week days	860
Ditto on Sundays	735
Ditto receipts for passengers per omnibus per week was	£14 16s. 0d.
Ditto fare per passenger	1·42d.
Ditto earnings per mile run	8·49d.
Total number of miles run	9,001,330

WORKING EXPENDITURE, HALF-YEAR ENDING JUNE 30, 1891.

	£	£	Per mile run. Pence.
General expenses		18,611	·49
Traffic ditto:—			
Road	85,652	119,781	3·19
Yard	34,129		
Maintenance ditto:—			
Horse stock	175,686		
Omnibus ditto	21,200		
Aprons	656		
Harness and stable utensils	6,189		
Furniture and fixtures	569		
Yard stock	639		
Stables, offices, &c.	3,679	209,419	5·58
Total		347,811	9·16

Provender, Including Cost of Preparation, Cartage, Lighterage, and Depôt Expenses for Half-year ending June 30, 1891.

Quarters.		£	s.	d.	£
16,173 oats	at	1	0	0	16,171
7,244 beans and peas	,,	1	14	4	12,431
48,016 maize	,,	1	7	7	66,277
3,576 bran	,,	0	9	11½	1,780
Loads.					
4,956 mixture	,,	3	4	0	15,852
4,210 straw	,,	1	14	1½	7,185
Sundry					332
Total					£120,028

According to Mr. C. T. Bray, each omnibus is allowed from 10 to 11 horses a day. To keep it running for from 12 to 14 hours 5 pairs of horses are worked, leaving 1 rest horse at the yard. On Sundays, only 4 pairs are working. There are, in all, about 10,000 horses. The average daily mileage run is 14 miles. The average life is from 4½ to 5½ years. Two horses are sold for every one that dies, or is killed. It is a hard life; the mischief is the continuous and frequent starting. It is the strain in setting a heavy omnibus in motion that tells. The omnibus weighs 33 cwt. When full inside and out there are 27 persons in and on the omnibus, besides the driver and conductor, making an average of about 3½ tons. As to accidents, very few horses are seriously damaged by falling on slippery pavements, of which asphalte is the worst.

PART III.

CONSTRUCTION OF TRAMWAYS.

CHAPTER I.

TRAMWAYS IN THE METROPOLIS.

SYSTEMS of tramway like those of Liverpool were adopted in the construction of the earlier portions of the tramways which were laid in London, under Mr. George Hopkins, as engineer, comprising the greater part of the North Metropolitan Tramways, of which the first section, from Whitechapel to Bow, was opened in May, 1870; and the original Metropolitan Street Tramways (now a part of the system of the London Tramways Company), 5¼ miles long, from Westminster Bridge to Brixton Church, Stockwell, Clapham Common, and Brixton Hill, also opened in 1870. The rails were of the form and section of the Liverpool rail, 4 inches wide, and 1⅜ inches thick, weighing 45 lbs. per yard. The system of construction, shown in Fig. 22, was similar to that at Liverpool. The stone pavement, or the macadam of the street, was taken out for a width sufficient for a double line, or a single line of tramway, as the case might be, including a clear space, 2 feet wide, beyond the outermost rails; and for a depth of about 9 inches, which was the depth of ordinary setts in the metropolis. In the open ground thus exposed, longitudinal trenches, about 9 inches deep and 16 inches wide, were excavated, corresponding to the position of the rails and the longitudinal sleepers by which they were to be supported. These trenches were filled with concrete made with Portland cement, or with hydraulic lime, mixed with river ballast, and made up to the level of the excavated ground, to form longitudinal foundations for the rails. The sleepers, 4 inches wide and 6 inches deep, were laid in cast-iron clip chairs, by means of which, with bar-iron cross-ties, dove-tailed at the ends, the gauge was maintained. The rails were spiked to the sleepers by vertical spikes through the grooves, with countersunk heads, and the structure was levelled up by concrete, packed under the sleepers, to form a foundation for the paving stones, and these were bedded on a layer of sand, and grouted and rammed.

The dove-tail tie-bars proved to be of little use; they were liable to rust away, and were wanting in precision, for unless the dove-tailings had been tightly and exactly fitted so that the chairs would have been prevented from shifting either inwards or outwards, the transverse connection was not sufficient to maintain the rails, when the support afforded by the pavement was removed or impaired. Besides, tie-bars placed between the paving sets are in the way, and interfere with the convenience for paving. Again, tie-bars laid in dove-tails in brackets, like those just described, work gradually to the surface, and even above the level of the paving. In such a contingency they are removed, which is the best thing to be done.

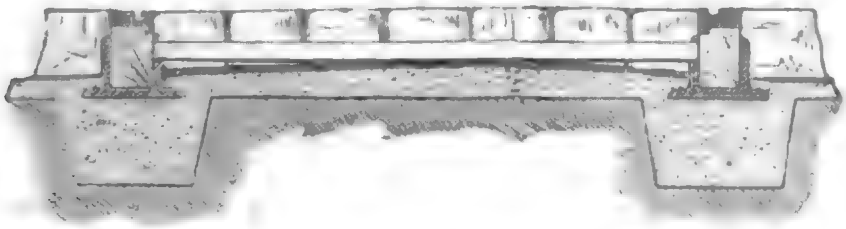

FIG. 22. North Metropolitan Tramway and London Tramways. First lines. Scale $\frac{1}{30}$.

Moreover, the flat rail and the vertical spike or bolt fastening make a defective combination. It is scarcely necessary to say that, at best, the form of the flat rail combined the maximum of material with the minimum of strength and stiffness, whilst the vertical spike fastening, though it is simple, and appears at first sight to have been happily devised, is deficient in strength and in durability, and contributes nearly nothing towards the union of the rail with the sleeper. The rail, especially at the joints, is liable to spring, and the spikes with their shallow countersunk heads and limited bearing surface, are liable to yield and to wear. The spikes in consequence are gradually loosened, and the heads are lifted, and torn or broken off. The spike heads are further exposed to damage from the wheel flanges, which, like the rail, become worn, ground in the groove, and occasionally split the rail.

Wherever there is vertical movement, of course an entry for water is made, pumping action ensues, and rain water ultimately sinks through the spikeholes and by the sides of the rails, and rises to the surface laden with sand and other detritus. The rails and sleepers are gradually undermined, the sleepers are deformed by blows, and the vertical instability is by so much increased.

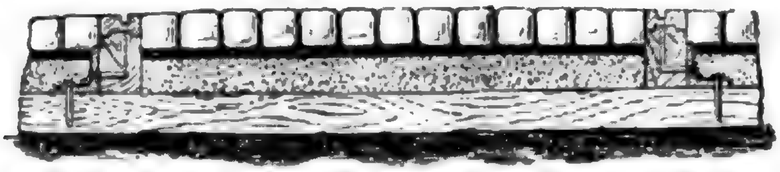

FIG. 23. Pimlico, Peckham, and Greenwich section of London Tramways. Scale, $\frac{1}{80}$.

With a view to ameliorate the difficulties of the vertical fastening, as well as to provide an iron tie of a substantial character in place of the delicate dove-tails, Mr. Joseph Kincaid, as engineer, employed transverse sleepers in the construction of the Pimlico, Peckham, and Greenwich section of the London Tramways, opened in August, 1871. Transverse sleepers, Fig. 23, were placed in the bottom of the excavation, to afford an increase of bearing surface on the ground and to receive the longitudinal sleepers which were placed upon them. The transverse sleepers, which were placed at intervals of 5 feet or 6 feet, also afforded a substantial means of tying longitudinal sleepers to the gauge. Instead of attachments in tension, like those of the dove-tailed bars, cast-iron brackets, two to each cross-sleeper, were employed as abutments, one bracket outside each longitudinal sleeper. The brackets were spiked to the longitudinal sleepers near to their lower surfaces, whilst they were extended up the sides of the sleepers, to afford a direct, or at least nearly direct, resistance to centrifugal stress. By this combination, the indirectness of the sleeper as opposed to lateral stress above, was liberally compensated by the general stiffness of the structure.

An additional fillet was applied to the under surface of the rail, Fig. 24, at the outside, sothat now the rail was formed with two fillets, one at each side, that it might be more firmly bedded on the sleeper than the rail having only one fillet. It was found necessary not only to provide, by the inside fillet, the means of resistance to the lateral stress of the cars through the flanges of their wheels, but, likewise, means of opposing the lateral action of cross strokes from the wheels of common road vehicles, which traversed the road in all directions. Hence the addition of the second fillet, at the outer side of the rails. The longitudinal sleepers were carefully rebated to receive the rails, which were fixed to them, as before, with vertical spikes through the groove. The adoption of the double fillet, though, in fact, a reversion to old-established American practice, constituted an intelligent advance in English practice with the grooved rail.

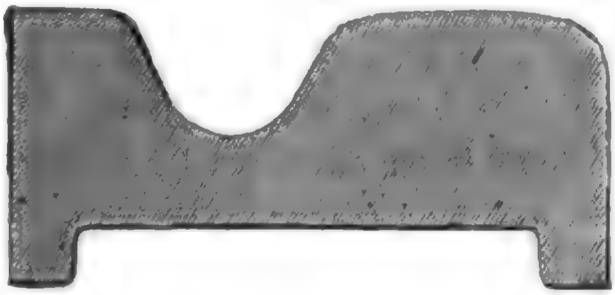

FIG. 24. London Tramways. Section of rail. Scale $\frac{1}{2}$.

The wearing surface of the rail was slightly rounded transversely, having about $\frac{1}{16}$ inch rise, by which the thickness was increased to $1\frac{7}{16}$ inches, though the motive for rounding is not obvious. The groove was made wider than before: 1⅜ inches at the surface; and it was rounded at the bottom to a circular form, thus at the same time strengthening the rail by the substitution of a round for a flat contour for the grooves, and facilitating the dislodging of detritus. The splay of the outer side of the groove was, at the same time, slightly greater than in the previous rail. The new rail was 4 inches wide, had a sectional area of 4¾ square inches, and weighed 48 lbs. per yard.

For laying in the foundation, the surface of the roadway was removed, and the ground was excavated to a depth of from 12 inches to 14 inches, to receive the cross-sleepers. After the longitudinal sleepers were laid and fixed, with the rails complete, they were brought up to the required level by concrete packing below the cross-sleepers; then the whole space was filled with lime concrete to a height necessary for receiving the pavement of stone or of asphalte, whichever was to be laid, for, in some parts of the way, asphalte was used instead of granite for paving. For asphalte, the concrete was required to be brought up higher than for stone, since it was only from 1½ inches to 2 inches deep, whilst stone was 6 or 7 inches deep; and the total cost of construction was greater for asphalte. Much was hoped for from asphalte as a pavement for tramways. Experience has not confirmed such expectations. Asphalte pavement breaks away at the borders next the rails, as well as at the outside, and it must be admitted that as a foothold for horses, in starting the cars, it has been a dead failure.

Mr. Hantingdon* gives particulars of the contractor's charge for constructing the way of the London Tramways. They may be taken as approximate actual costs for tramways in London. The gauge of the way is 4 feet 8½ inches; the interspace between the lines is 4 feet. The rails were fixed with ⅝-inch staples on the kyanised longitudinal sleepers, 21 feet long, with four transverse sleepers, bolted with ¾-inch bolts and nuts to the gauge. The fish-plates at the joints were 9 inches long and ⅜ inch thick, let into the longitudinal sleepers. The sleepers were bedded in Portland cement concrete, 6 inches deep, upon which the paving was laid.

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* *Proceedings of the Institution of Civil Engineers*, vol. 50, 1877, page 28, in the discussion of Mr. Robinson Souttar's Paper on "Street Tramways."

LONDON TRAMWAYS—SINGLE LINE.

	Per yard.	
	s.	d.
Rails, 50 lbs. per yard, ties, spikes, bolts, staples, fishes, &c., rails at £10 10s. delivered	10	6
Timber creosoted and shaped	2	0
Fixing and laying, including crossings	1	0
Maintenance for one year		6
Contingencies, cartage, lights, watching, waste, and cutting	1	6
Risk and profit, 10 per cent.	1	6
Total . .	17	0

1,760 yards at 17s. = £1,496, say £1,500 per mile.

The cost for paving with granite stones, 7 inches deep, for a double road, with concrete bottom, was as follows:—

DOUBLE LINE.

	Per square yard.	
	s.	d.
Granite paving sets, 7 inches deep, tramways 18 feet wide, materials and labour	11	0
Concrete, averaging 6 inches deep, including excavation and removal of road	1	6
Contingencies, grouting, carting, watching, removing materials and sanding	1	0
Maintenance for one year	0	3
Risk and profit, 10. per cent	1	3
Total . .	15	0

1,760 yards × 60 yards × 15s. = £7,920, say £8,000 per mile.

The cost for paving, single line, is half the above-given amount, or £4,000; and the total cost of the tramway is made up thus:—

	Per mile.
Way	£1,500
Paving	4,000
Per mile, single line .	£5,500

Or £11,000 per mile, double line.

Extra works, crossings, and sidings are not included in these estimates.

Mr. Kincaid, having in the Peckham Tramway proved the advantage of the cross-sleeper as a useful element in a timber structure, employed it in the construction of the first section of the Leeds Tramways—the line to Headingley—which was opened in October, 1872. The gauge was 4 feet 8½ inches. The ground was excavated to a depth of 7½ inches—the depth of the rail plus that of the longitudinal sleepers—for the whole width of the way; and trenches about 9 inches wide were cut in the excavated bottom, and filled with concrete, flush with the bottom, to carry the sleepers. The cross-sleepers, 6 inches wide and 4 inches deep, were laid in the concrete of the transverse trenches about 3 feet apart, flush with the surface; and thus a continuous level foundation was formed for the longitudinal sleepers and the rails. The longitudinals, 4 inches wide and 6 inches deep, were fixed to the transverse sleepers by cast-iron brackets, one on each side of each longitudinal sleeper, spiked to both timbers. The rails, weighing 47½ lbs. per yard, were flat grooved, 4 inches wide and 1¼ inches thick, with two ½-inch square fillets on the underside, let into the sleepers; they were spiked through the groove to the sleepers. A bedding of furnace ash or clinkers, 2¼ inches thick, was laid over the bottom, on which paving sets 5 inches deep were laid.

On this system, an economy of excavation, as well as an economy of concrete, was effected, by employing concrete for the support of the sleepers exclusively. By the interposition of a bed of ashes laid uniformly over the whole surface, it was designed that the pavement should rest equally over the sleepers and the direct excavated surface.

INCLINES AND CURVES ON TRAMWAYS IN LONDON.

The steepest gradient of considerable length on the North Metropolitan system is one in the City Road, of about one in forty, on the approach to the Angel at Islington. There are short pieces at the crossings of canal bridges of about one in twenty-five. The curves are 40 feet radius; with reverse curves of 50 feet radius.

On the London Street Tramways the gradients are easy, excepting a short piece of one in twenty-three. The quickest curves have a radius of 30 feet.

On the London Tramways the prevailing gradient is one in fifty, but there are gradients of one in thirty.

CHAPTER II.

LARSEN'S FASTENING.—LONDON STREET TRAMWAYS.—BELFAST TRAMWAYS.

BUT a method of fastening the rail to the sleeper was wanted which would be free from the defects of the vertical spike,—a method the barbarity of which was only rivalled by its simplicity. Mr. Jorgen Daniel Larsen supplied the want, by substituting lateral fastenings for vertical spikes, a system which was patented by him in February, 1871, and is represented in Fig. 25.

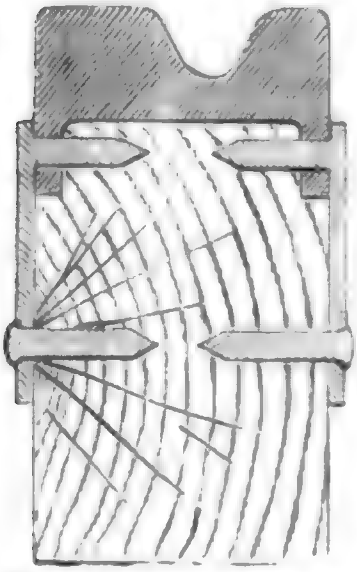


FIG. 25. Side fastening. By Mr. J. D. Larsen. Scale ¼.

"The vertical or upright side of the rail," he says, "intended to be fastened to a sleeper, is so made as to extend in the manner of a flange or flanges below the upper surface of the sleeper (longitudinal), either on one or both sides of the sleeper. An aperture is made in each flange, so as to be a short distance below the upper surface of the sleeper, when the rail is placed thereon. To fix the rail to the sleeper, a bent metal piece or half staple is inserted into the hole in the flange and driven home, and is also fixed to the vertical side of the sleeper. The part of the metal piece or half staple inserted into the hole may be of various forms, and may be so long as to go through the sleeper and to enter also a corresponding hole in the other vertical side of the rail extended as a flange. The metal piece may be of such form as to pass through at once two or more holes in the same flange."

In the Larsen rail two important advantages are combined. By the flanges it is virtually increased in depth and in stiffness vertically and laterally ; and the fastenings, as applied at the sides, are not only removed from interference of the wheel flanges, but are so placed as greatly to strengthen the attachment of the rail to the sleeper ; for it is apparent that the wide base of attachment afforded by the lateral flanges creates a leverage of resistance to lateral stress twice as great as the leverage derived from a central vertical spike. There is yet another advantage, that by means of the flanges the sleeper may be more firmly embraced by the flanged rail than it can possibly be by the shallow filleted rail.

Although, incidentally, the strength of the Larsen rail was increased by the addition of the flanges, it does not appear that vertical strength was, in his earliest designs, made a point in question by the designer; for there is only sufficient depth of flange, 1 inch, to afford room for the fastenings. In point of absolute transverse strength, Larsen's rail had already been anticipated by Livesey's rail, patented in 1869, which is described, and which was formed with a flange each side of considerable depth. Mr. Larsen should, nevertheless, be credited with the merit of introducing the flange rail into practice in England, as well as the method of the side fastening.

In the construction of the London Street Tramways, under the charge of Mr. Larsen, the first portion of which was opened in November, 1871, he designed and made the first application of lateral fastenings for tram-rails (Fig. 26), upon the results of which his patent was based. In this, his first trial, the rails were 4 inches wide, and weighed 60 lbs. per yard. They were double flanged, and were fixed upon longitudinal sleepers, 6 inches deep, by means of side fastenings, which consisted of three pieces at each side :—a strap 3¼ inches long, ⅝ of an inch wide, and ⅜ inch thick, the two spikes driven horizontally into the sleeper, through a hole at each end of the strap, the upper spike passing also through a hole made

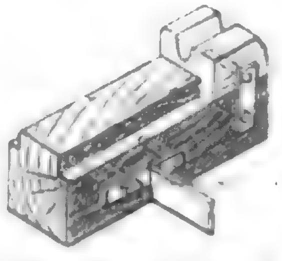


FIG. 26. Larsen's fastening for the London Street Tramways.

in the flange of the rail. The excavation for the foundation was carried down to a level of 4 inches below the underside of the sleepers, for the whole width of the way. An even bed of concrete, 4 inches thick, was laid upon the bottom, and the longitudinal sleepers were laid directly upon it. The timbers were placed in cast-iron chairs at the joints, and the gauge was fixed by means of flat bar-iron ties, split and kneed both ways at the ends, and fixed to the sleepers by bolts or spikes as shown. A 2-inch layer of sand or of gravel was distributed over the concrete surface, to form a bed for the paving, which was laid and grouted in the usual manner. (See Fig. 27.)

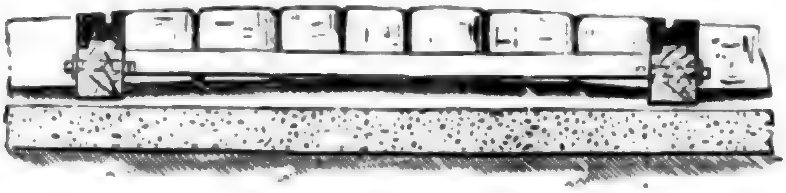


FIG. 27. London Street Tramways. Scale $\frac{1}{30}$.

In this his first employment of side-fastenings, Mr. Larsen substituted three pieces for the vertical spike. Not oblivious of the disadvantage of multiplying the number of pieces in the fastening, he reduced them in his patent to two in number, as has already been described; and in his next operation, the construction of the Belfast Tramways, he employed the fastening in two pieces, as patented. The works of these tramways were commenced early in 1872, and the first section was opened in the autumn of the same year.

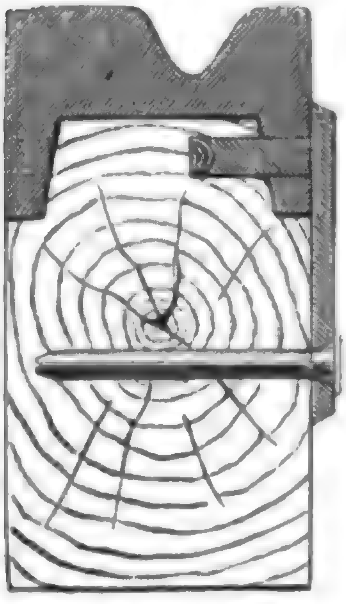


FIG. 28. Belfast Tramways. Section of rail with Larsen's fastening. Scale $\frac{1}{4}$.

The construction of the Belfast Tramways is illustrated by Fig. 28. It consists of longitudinal sleepers laid upon cross-sleepers enclosed in concrete, the rails being laid on the longitudinal sleepers. The gauge of the way is 5 feet 3 inches. The intermediate space between the two lines of rails of a double line is 4 feet; the breadth of paving at the outer sides of the rails is

2 feet; the tread of the rails is 1⅞ inches wide, and the total width of the tramway for a double line is constituted as follows:—

	Ft.	In.
Two lines, 5 feet 3 inches gauge	10	6
Intermediate space	4	0
Two outside breadths of 2 feet each . . .	4	0
Four widths of tread 1⅞ inches	0	7½
	19	1½

The ground was excavated to a uniform depth of 11½ inches below the permanent surface, for the whole width of the tramway, double or single. Cross-sleepers of wood, 4 inches deep by 6 inches wide, and 7 feet in length, were laid on the bottom of the excavation at intervals of 5 feet between centres, and the longitudinal sleepers, 3⅞ inches wide, and 6 inches deep, were laid and fixed by cast-iron brackets, weighing 5 lbs. each. There was but one bracket at each intersection, placed alternately at the inside and the outside of the longitudinal sleeper; fixed by four spikes to each bracket.

The rails weigh about 62 lbs. per yard; they are 3⅞ inches wide and 1½ inches thick; the side flanges are 1¼ inches deep, and ⁷⁄₁₆ inch thick at the edge, making the total depth of the rail 2¾ inches. The tread is 1⅞ inches wide, the groove is 1⅛ inches wide and ¹¹⁄₁₆ inch deep, and the outer ledge is ⅜ inch thick at the edge. The side fastening of the rail to the sleeper is of two pieces:—an iron plate or strap, ¾ inch thick, having a spike welded to it at the upper end, which passes through the flange or the rail, and a hole near the lower end, through which a large spike is driven nearly through the sleeper. The fastenings were applied alternately to each side of the rail at short intervals.

After the sleepers and rails were accurately adjusted and packed below the cross-sleepers, the spaces between the cross-sleepers, and the whole area above them on each side of the longitudinal sleepers, were filled solid with concrete to a total height of about 7 inches above the floor of the excavation, suited for the laying of the paving, which consisted of 4 inches granite cubes with a ½-inch layer of sand.

CHAPTER III.

RECONSTRUCTION OF THE NORTH METROPOLITAN TRAMWAYS.

In the work of reconstructing the North Metropolitan Tramways in 1877, Mr. Hopkins abandoned the cast-iron chairs or clips with the dove-tailed cross tie-bars for connecting the tails, and substituted a tie-bar, Fig. 29, of the same scantling as before, formed with a ¾-inch bolt at each end, which was passed through each longitudinal sleeper, and screwed up with a shallow nut outside. The tie-bar was brought up with a square shoulder on a washer, to the inside of each sleeper; the nut was only ¼ inch thick in order to minimise the projection, and consequent

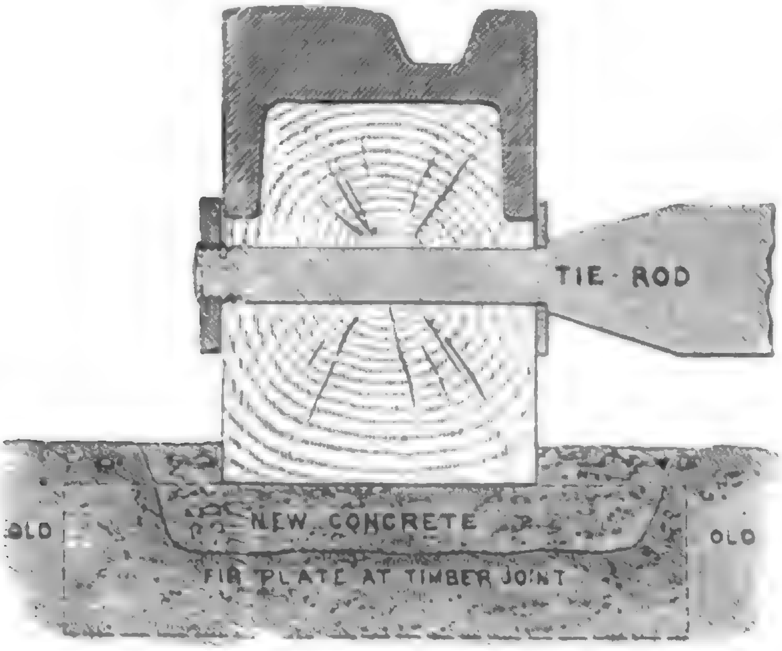


FIG. 29. North Metropolitan Tramways:—Method of Reconstruction. Scale ¼.

interference with the paving at the other side of the sleeper. The existing foundation was partly renewed by the excavation, under each sleeper, of a shallow trough in the concrete, 1½ inches deep and 6 or 7 inches wide. This trough was filled with fine concrete in which the longitudinal sleepers were embedded to the depth of ½ inch. The sleepers were 4 inches wide and 5 inches deep, rebated to fix the rails. They were bedded at their joints on plates of fir, 8 inches wide and 2 inches thick, let into the foundation. The rails were of steel, weighing 60 lbs. per yard. They were of the box type, 3⅞ inches wide at the surface, 2¾ inches deep over the flanges, and 1 5/16 inches thick. They resembled in section the Vale of Clyde rail; they had the same total depth, but they were not so thick as the other rail. The groove was 1¼ inches wide and ¾ inch deep, having only 9/16 inch of metal below the groove. The tread was 2 inches wide, and was very slightly rounded; the flanges were ⅜ inch thick at the edge. Each rail of 24 feet in length was fastened by 25 staples, placed at a pitch of 2 feet 7 inches at each side, except those at the ends, where there were two pairs of staples, of which one pair was distant 1½ inches from the end of the rail, and the second pair was 3 inches farther off.

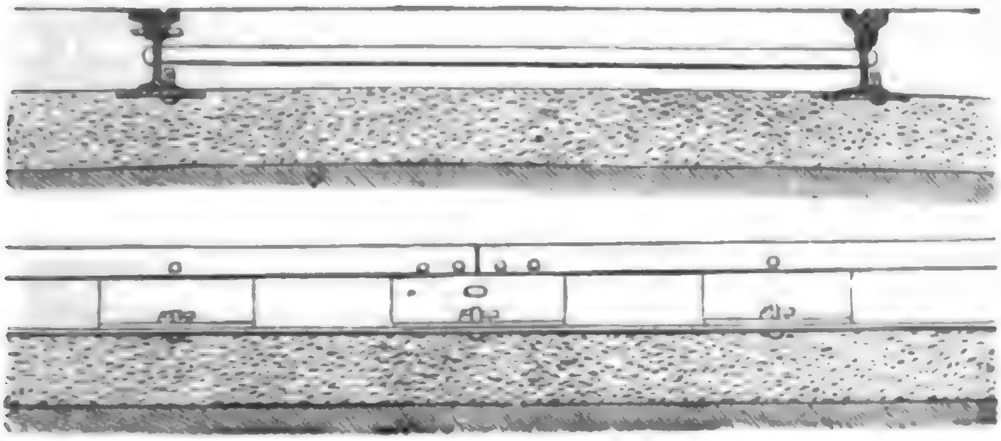
This mode of reconstruction was followed until the end of 1880, when 18 miles of single way had been reconstructed. In some places a longitudinal plank, 11 inches wide by 1½ inches thick, was laid below the sleeper and spiked to it, in order to prevent sinkage of the adjoining paving sets by partially supporting them. The spikes consisted of 3½-inch nails driven down from the sides diagonally. In 1880, a length of 3 miles of new line had been laid with the plank base, and about 2 miles of old line had been reconstructed with it. The work of reconstructing old lines on this system was done principally in Liverpool Road, Islington, and the new lines were laid in Dalston Lane and Graham Road, Dalston, and on the line through Victoria Park to its northern terminus. The work gave satisfaction, excepting at a few places where the paving sets were not of a suitable depth, or where the traffic was admitted over the work before the grouting was sufficiently set.

The employment of the plank base in reconstruction involved the breaking up of much of the concrete foundation, which on the North Metropolitan system generally is very hard. The cost of breaking up actually exceeded the cost of making everything good with Portland cement.

The rails, again, were reduced to a width of 3⅜ inches, mostly by reducing the thickness of the guard flange, for it was ascertained that guards of the thickness of ½ inch or even slightly less than this, are worn down by the ordinary vehicular traffic at nearly the same rate as that at which the head of the rail was worn by the ordinary traffic and the car traffic combined. Such equality of wear has its importance, for it has frequently become necessary to reconstruct lines of way having ¾-inch guards several years earlier than would have been necessary had the tread not worn down much more rapidly than the guard. The slight rounding of the tread of the new rails has not been found to serve any useful purpose, and has therefore been abandoned, and the tread has been made square. The groove was reduced to a width of 1$\frac{1}{16}$ inches at the surface, which was believed to be the minimum width that was practicable, having proper regard to the resistance of the car and the work of the horses.

But, the box-rail laid with longitudinal sleepers, though as good as most other systems, and probably better than any of these, was wanting in permanency, and in any case was unsuited for mechanical tractors. Short lengths of other systems were laid down for trial. The metal system of Winby and Levick was tried experimentally, a length of 80 yards of single line having been laid early in 1879 in Upper Street, Islington. It was, and continued to be (1880), in good order.

A trial length of 15 yards of toughened glass sleepers, 4 inches by 6 inches deep, to the same section as the rebated fir sleepers, was laid in High Street, Stratford, about the middle of 1879, and covered with the ordinary box-rail. Whilst the new material seemed to be fully capable of supporting the road without failure by crushing, it was broken into short segments, some pieces being not more than 6 inches in length, and the fractures were nearly vertical. As the level of the rails was not affected by the fracturing, the sleepers were allowed to remain where they were. The rails were fastened to the sleepers by means of straps passed under these. The straps worked loose and were not a success.



FIGS. 30 and 31. Page's System, North Metropolitan Tramways. Scale $\frac{1}{12}$.

The system of Mr. William Page was finally selected for the renewals and extensions of the system, and a length of renewal on this system was commenced to be laid at the end of 1880. It was designed also for the extension at Leytonstone. The system, Figs. 30 and 31, consisted of a steel rail, Fig. 32, weighing 42 lbs. per yard, grooved on the underside, to fit on and be supported by wrought-iron standards, which rested upon and were pinned to a continuous longitudinal iron plate or sleeper, laid on a bed of concrete. The tread of the rail was perfectly flat, and had a width of 1 $\frac{7}{8}$ inches, the groove is 1 $\frac{1}{16}$ inches wide, and the flange or guard is $\frac{1}{2}$ inch wide, making together a width at the surface of 3 $\frac{7}{16}$ inches. The groove was $\frac{5}{8}$ inch in depth, and the sides were sloped equally. The depth of the rail was 2 $\frac{1}{2}$ inches. The

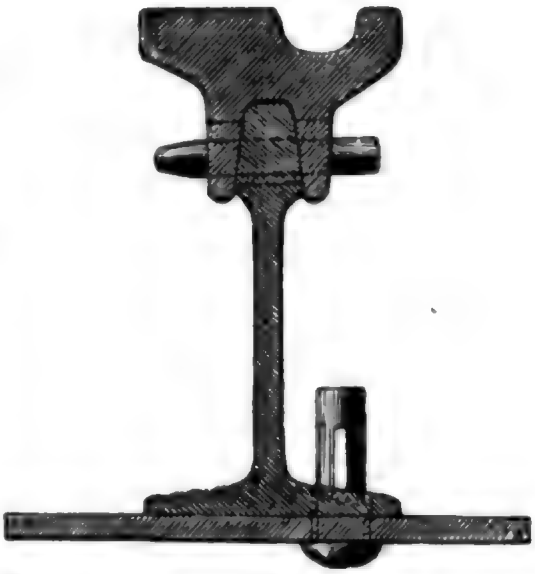


FIG. 32. Page's Way, North Metropolitan Tramway. Scale $\frac{1}{4}$.

groove at the lower side was 1¼ inches deep to give bearing vertically and laterally on the supports, the flanges forming the groove being 5/16 inch thick at the edge. The standards are of an inverted T section, 5½ inches high, 3⅜ inches wide at the base, and of a length of 12 inches, except at the joints, where they are 14 inches long. The thickness of the web is ⅜ inch, and the foot averages the same. The head is ⅞ inch thick, tapering upwards to ⅝ inch in a height of 1¼ inches. The standards are placed 12 inches clear apart; the rails are secured to the standards by means of plain round pins passed right through the taper bearings, four at each joint and one at each intermediate standard. The pinholes are so arranged that the driving of the pins draws the rail down into close contact with the standard and makes a tight bearing. The longitudinal base plate is 7 inches wide and 5/16 inch thick; the standards are each fastened to it by one ⅝-inch pin with double cotters.

The total height of the way thus constructed was 7 inches. It is bedded on a foundation of concrete 6 inches deep, composed of one part of blue lias lime and six or seven parts of ballast. The width of the bearing of the permanent way on the concrete obviated the necessity for using Portland cement.

Gauge-ties of wrought-iron bars 2 inches by 5/16 inch thick, secured to the standards, were placed at intervals of 20 feet. They were thickened at the ends to a thickness of ½ inch and were notched. Through the web of each of the two standards to be tied a hole 2 inches long horizontally and ⅝ inch deep is made. Through the two holes the tie is inserted and then turned a quarter round to a vertical position edgewise. Thus placed the tie holds the two standards firmly, and it comes between two courses of paving sets by which it is maintained in position. But as the permanent way is solidly constructed, and the base plate is embedded in the concrete, it was considered that the ties were scarcely necessary, and they were therefore to be discontinued.

The paving used was 6 inches in depth, chiefly of Guernsey granite. The sets were bedded on a layer of fine gravel, and were rammed perfectly flush with the rails. The sets laid next the rails were prevented from sinking by the base-plates of the way, which extended laterally about two inches under the paving. To compensate for the slight variations in the depth of the sets, as well as to prevent the disintegration of the grouting in the joints of the paving, which would result if the sets were in direct contact with the elastic iron base-plates, the depth of the permanent way was made sufficient to admit of ½ inch or ¾ inch thickness of bedding below the sets over the plates.

The rails, as before stated, weighed 42 lbs. per yard, and the base-plates 22 lbs. per yard. The joint standards weighed 13¼ lbs. each, and the intermediate standards 11¾ lbs. each. The cotter-bolts weighed one ton per mile, and the cotter-pins for the rails ½ ton per mile; the cross-ties weighed 26 cwt. per mile.

In proceeding with the work of reconstruction and renewal, after the way was lifted, a thin stratum, an inch or so in thickness, was picked off the old concrete bed, where it was in good condition, and the vacancy was made good under the base-plate with fine concrete. Where the old concrete was in bad condition it was entirely removed. The parts of the iron way were put together in the excavated space, propped on temporary packing of wood or other material, so that the base-plate was sufficiently elevated above the floor of the excavated space to admit of the holding-down bolts being inserted. When the whole of the metal work was erected it was lifted bodily into its permanent position by means of levers, and was temporarily repacked up with blocks 6 feet or 8 feet apart. The new concrete was then deposited and packed under the base-plate. When it was stiff enough to bear the weight of the way—which it usually became in the course of an hour or two—the temporary packing was removed, and its place was filled with concrete. The space between the rails was filled in with concrete to the proper level required for the support of the paving.

In packing the rails with concrete it was put in from one side only, and shovel-packed from that side, and the packing was continued until it was driven out in a full body at the other side of the rail. When the clear space below the base-plate to be packed up was but one or two inches deep, it was especially needful that the packing should be accomplished as above described, otherwise it might frequently have happened that the concrete only advanced an inch or so under the base-plate at each edge, leaving the interior unsupported.

The granite sets on the North Metropolitan Tramways vary in depth from 4 inches on some routes to 9 inches on others. On most of the lines 6-inch sets are used. They are laid over a layer of gravel or shingle, from an inch to 1½ inches in thickness, which is compressed by the ramming of the pavement to a thickness of from ½ inch to ¾ inch. Frequently a little dry lime is mixed with the bedding. With respect to the width of the pavement laid by the Tramway Company, the local and the road authorities generally succeed in enforcing claims on the Tramway Company, before Parliamentary Committees, by which it is compelled to have a greater width than the usual and sufficient allowance of 18 inches outside of the way.

The cost of Mr. Page's system of tramways, taken as new, is here given, followed by the cost for reconstruction :—

QUANTITIES AND COSTS PER MILE, SINGLE LINE, OF PAGE'S SYSTEM. NORTH METROPOLITAN TRAMWAYS, MARCH, 1881.

		£	s.	d.
Breaking up macadam road and excavating to depth of 12½ inches and removing surplus, 4,981 square yards . . .	@ 1s.	249	1	0
Blue lias lime concrete, 6 inches deep, 4,981 square yards	„ 1s. 9d.	435	17	0
Steel rails, 42 lbs. per yard, 66 tons.				
Wrought-iron bearers, 12 inches long, 4,752 @ 11¾ lbs. each, 24 tons 18 cwts. 2 qrs. 4 lbs.				
Wrought-iron joint bearers 14 inches long, 528 @ 13¾ lbs. each, 3 tons 4 cwt. 3 qrs. 8 lbs.				
Wrought-iron plates, 22 lbs. per yard, 34 tons, 11 cwt. 1 qr. 16 lbs.				
Total, 128 tons 14 cwt. 3 qrs. . . .	„ £8 5s.	1,062	1	9
Carried forward		£1,746	19	9

		£	s.	d.
Brought forward		1,746	19	9
Wrought-iron ties, 264 @ 11 lbs. each, 1 ton 5 cwt. 3 qrs. 20 lbs.	@ £7 10s.	9	14	7
Cotter bolts and keys (5,280), 1 ton		16	10	0
Rail pins (7,862), ½ ton.	„ £13 10s.	6	15	0
Laying, watching and lighting, 1,760 yards	„ 2s.	176	0	0
Total cost, exclusive of paving		1,955	19	4
Paving, say 6 inches by 4 inches, granite sets, laid and grouted, 4,688 yards	„ 11s.	2,728	8	0
Total		£4,684	7	4

Renewal and Reconstruction of Way on Page's System, 1881.

		£	s.	d.
Take up paving next rails and defective parts, say half total area, 2,344 square yards	@ 6d.	58	12	0
New steel rails, 66 tons				
New bearers, say 10 per cent. of original quantity, 3 tons				
Total, 69 tons	„ £8 5s.	569	5	0
Rail pins, ½ ton	„ £13 10s.	6	15	0
Laying new rails, lighting and watching 1,760 yards	„ 1s.	88	0	0
Necessary dressing and relaying paving with 20 per cent. new stone, 2,344 yards	„ 6s.	703	4	0
Credit old rails, &c., say		179	0	0
Total cost, including paving		1,246	16	0

The North Metropolitan Tramways are now (1892), and have recently been, in course of entirely new reconstruction, in which all other systems of way on these tramways have been superseded and replaced by the steel girder rail.

CHAPTER IV.

RECONSTRUCTION OF THE LONDON AND LONDON STREET TRAMWAYS.

LONDON TRAMWAYS.

THE way of the London Tramways was renewed in 1879—80, with the Aldred-Spielmann rail, illustrated by Figs. 33 and 34. The two half-rails, Fig. 34, which are of steel, are laid so as to break joint in the chairs, and are fixed in position by a wooden key. The bearing-rail takes a square bearing on the raised seat

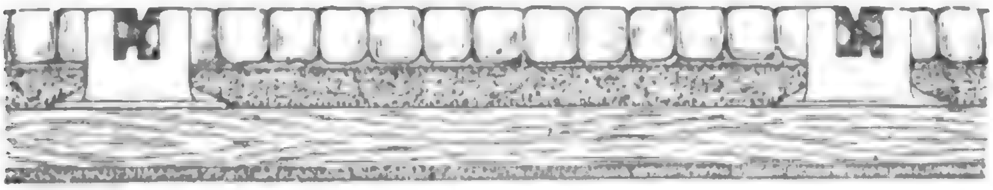


FIG. 33. The Aldred-Spielmann Way, London Tramways. Scale $\frac{1}{24}$.

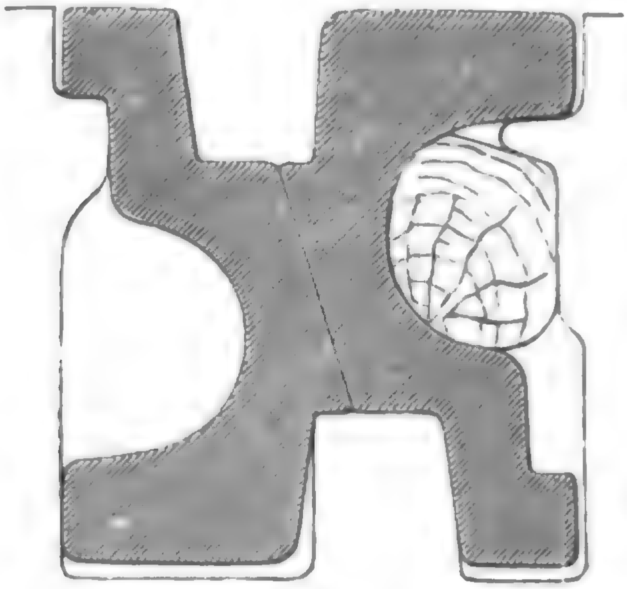


FIG. 34. The Aldred-Spielmann Rail, London Tramways. Scale $\frac{1}{2}$.

at the bottom of the opening of the chair, and by its inclined surface of contact it holds the guard rail in place. Each half-rail is 21 feet in length; it weighs 32 lbs. per yard; making for the whole rail 64 lbs. per yard. The tread of the rail is 1⅝ inches wide, the groove is 1 inch wide and 1 inch deep, and the guard is ¾ inch wide at the surface; making the whole width 3⅜ inches. The rail is 3⅝ inches in depth. The chairs are hollow castings, combining strength and comparative lightness, though weighing 37½ lbs. each—in consideration of the double function of holding the half-rails together and the maintenance of the break-joints of the two halves with each other. They give a bearing for the rails 4 inches long, and as they are placed at 3 feet apart between centres, the net space between the chairs is reduced to 2 feet 8 inches. The chairs are screwed down on transverse timber sleepers, 4½ inches deep, 9 inches wide and 6 feet 6 inches long. The height of the chair is 7½ inches, by which room is provided for 4-inch or 5-inch sets, clear of the spike heads. Added to the depth of sleeper, 4 inches, and 1½ inch more to the bottom of the excavation, the total depth of the excavation amounts to 13 inches below the level of the rail. A bed of Portland cement concrete, 8½ inches deep, is brought up from the bottom of the excavations, enveloping the sleepers. A ½-inch layer of sand is spread over the surface, and 4-inch cubes are laid as paving.

The following is the cost for one mile of the Aldred-Spielmann double way. The rails cost £5 5s. 0d. per ton in 1879, and £6 17s. 6d. per ton in 1880; average, say, £6 per ton; chairs, £4 per ton; screws, £15 per ton:—

QUANTITIES AND COST PER MILE, DOUBLE LINE, OF THE ALDRED-SPIELMANN WAY—LONDON TRAMWAYS, 1879—1880.

		Per mile. £	s.	d.
Steel rails, 64 lbs. per yard, 200 tons . .	@ £6	1,200	0	0
Cast-iron chairs, 116 tons	,, £4	464	0	0
Screws, 5 tons	,, £15	75	0	0
Carried forward		£1,739	0	0

		Per mile. £	s.	d.
Brought forward		1,739	0	0
Sleepers, 3,520	@ 1s. 10d.	322	14	0
Keys, 7,040, per thousand	,, £3	21	2	0
Concrete, 2,100 cubic yards	,, 13s.	1,365	0	0
Sand, 1,760 lineal yards	,, 6d.	44	0	0
Excavation, &c., 9,973 square yards	,, 1s.	498	13	0
Laying, watching and lighting, 1,760 lineal yards	,, 4s.	352	0	0
Total cost per mile double line, exclusive of paving		4,342	9	0
Do. do. single line, do. do.		£2,171	4	6

There are now (1892) six different sections of rails in the ways, comprising a light section and a heavy section of the Aldred-Spielmann rail, the Rymney or box rail, the Gowans girder rail, a rail laid in chairs, of a deck beam section, and a girder rail of recent sections. The Gowans way was laid in 1879, in the Brixton Road, for a length of 1¼ miles. This rail, Fig. 35, which was patented in 1878, is a modification of the girder rail, in which the lower flange is wider at the outer side, under the tread, than at the inner side. Openings are made through the web of the rail at short intervals, in order to lighten the rail,

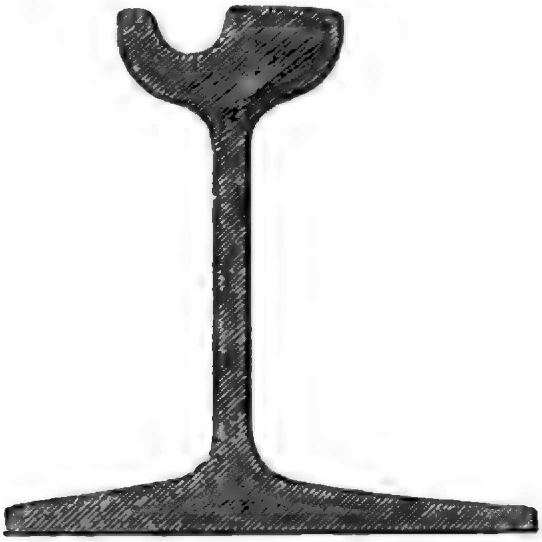


FIG. 35. Gowans Girder Rail. Scale ¼.

and to admit of the bonding of concrete packing of the rails. This system was laid experimentally in Edinburgh in 1877—78. It has also been laid in Dundee, Manchester, Sunderland, and London.

The Gowans rails are of steel, rolled in lengths of 27 feet, and they weigh 85 lbs. per yard. They are 7 inches in depth, and the base is 7 inches wide, placed eccentrically to the web, for the reasons already explained. The tread is 1$\frac{9}{16}$ inches wide, the groove is 1 inch wide, and the guard-flange is 1$\frac{7}{16}$ inches wide; making together a width of 3 inches. The web is fully ⅜ inch thick at the central part, tapering to a thickness of fully $\frac{5}{16}$ inch at the upper and lower parts. The base is ⅝ inch thick near the web, and tapers in thickness to ¼ inch at the edges. The rails are fished with plates weighing 18 lbs. per pair. Each rail is laid direct on a longitudinal bed of concrete 15 inches wide and 6 inches deep, as shown in Fig. 36. Between and outside the longitudinal beds of concrete and the rails, a bed of concrete 6 inches deep is laid for the entire width of the excavation, to support the paving. It is laid on the floor of the excavated space, 10½ inches below the surface, such that above the concrete there is depth for a ½-inch layer of sand and 4-inch paving cubes. The bases of the longitudinal beds of concrete are 13 inches below the surface, comprising 6 inches for the concrete and 7 inches for the rail. The wide bed of concrete overlaps the longitudinal beds by a depth of 2½ inches, and to this extent the rails are embedded in it and secured to the gauge; though it is difficult to perceive in what way the openings in the webs of the rails peculiar to Mr. Gowans' system are utilised, for, whilst the ostensible purpose of the openings, called "quatrefoils," though in reality trefoils, is to permit of the bonding of concrete through

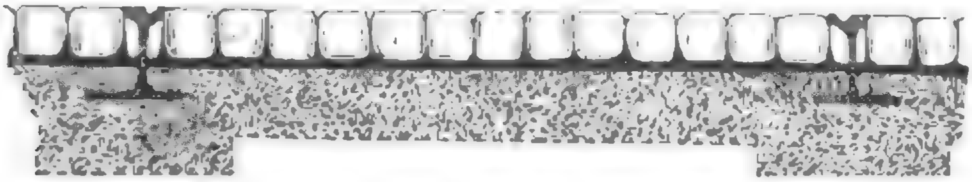


FIG. 36. Gowans Way, London Tramways. Scale $\frac{1}{24}$.

the rail, the concrete scarcely reaches above the lower sides of the openings. On a ½-inch layer of sand, 4-inch paving cubes are laid, flush with the rails.

QUANTITIES AND COSTS PER MILE, DOUBLE LINE, OF GOWANS GIRDER RAILWAY—LONDON TRAMWAYS, 1879.

		£	s.	d.
Steel rails, 85 lbs. per yard, 267 tons .	@ £8 10s.	2,270	0	0
Fish plates, 6 tons 6 cwt.	,, £8	50	8	0
Bolts and nuts, 1 ton 8 cwt.	,, £20	28	0	0
Concrete, 1,866 cubic yards	,, 13s.	1,212	18	0
Sand, 1,760 lineal yards	,, 6d.	44	0	0
Excavation, &c., 9,973 square yards . .	,, 11d.	457	2	0
Laying, watching and lighting 1,760 lineal yards	,, 4s.	352	0	0
Cost of way, per mile, double line		4,414	8	0
Do. do. single line		2,207	4	0

THE LONDON STREET TRAMWAYS.

These tramways were laid originally on the Larsen system of way. The way has been to a great extent (1892) replaced by girder rails weighing 90 lbs per yard. The girder rail has also been laid on all new lines for the last seven or eight years.

CHAPTER V.

RECONSTRUCTION OF THE SOUTH LONDON TRAMWAYS.

Meakins' system of way, Fig. 37, as originally adopted for the Southwark and Deptford Tramways, under the direction of Mr. W. Shelford, the engineer; and for the South London Tramways, in the Battersea District, under the direction of Mr. A. J. D. Cameron, the engineer, was arranged by Mr. John Dixon, the contractor for both of these works. The gauge of the ways is 4 feet 8½ inches. The rail, Fig. 38, is composite, consisting of a steel rail, having a central web, weighing 52 lbs. per yard, riveted to and between two angle-irons, weighing each 30 lbs. per yard, making together a compound rail weighing 112 lbs. per yard, of a total height of 8 inches. The angle irons, rolled with comparative facility, are 3 inches by 6 inches high, and ⅝ inch thick, and forming a base 6½ inches in width. The rail is

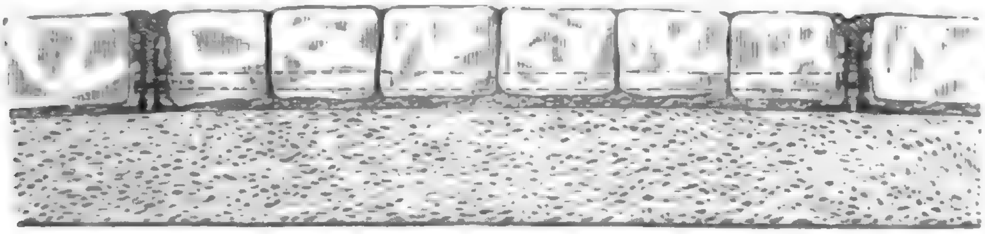


FIG. 37. Meakins Way, Southwark, Battersea. Scale 1/24.

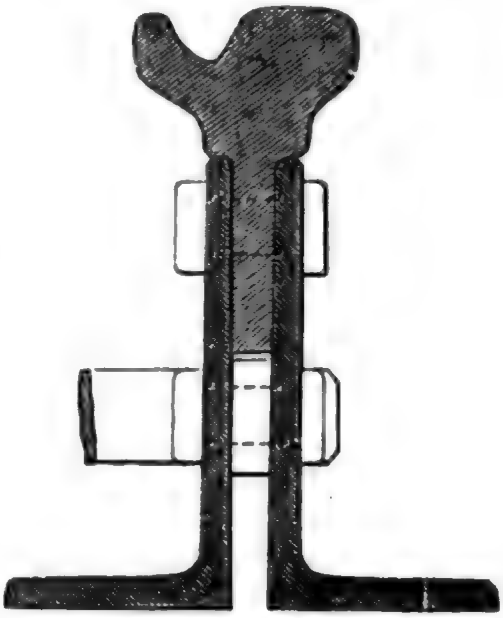


FIG. 38. Meakins Way, Southwark, Battersea.—Rail. Scale ¼.

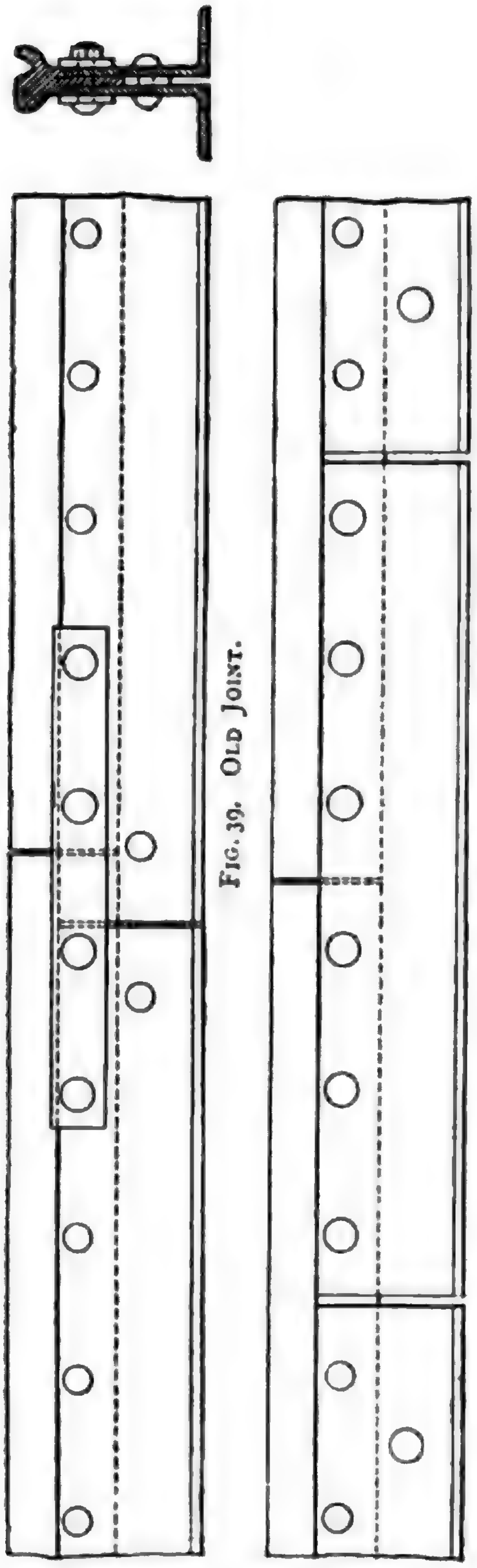


FIG. 39. OLD JOINT.

FIG. 40. NEW JOINT.

FIGS. 39 and 40. South London Tramways: Rail Joints. Scale 1/12.

4½ inches deep, the head being 2 inches deep, and 9/16 inch in thickness. The tread of the rail is 1¼ inches wide, the groove is 11/16 inch wide and ¾ inch deep, and the guard flange is 7/16 inch wide; making together a width at the surface of 2⅜ inches. The guard flange, it should be noted, is lower than the tread. The rail is joined to the angle-irons with ¾-inch rivets, at 6 inches of pitch; and the angle-irons are riveted together at intervals of two feet, except at the junction of two lengths, where the rivets are only six inches apart. The rails are 24 feet in length, and break joint with the angle-irons to the extent of 2 inches; and are thus held in line. They are also fished with flat plates and four bolts and nuts (see old joint, Fig. 39).

The rails are held to gauge by wrought-iron tie-rods, 1¼ inches by ¼ inch thick, three to [illegible] length of rail, notched [illegible] ends, passed through horizontal slots in the heads of the rails, and turned into a vertical position so as to hold the rails in gauge.

The foundation consists of a bed of Portland cement concrete, 11 inches deep and 11 feet wide, comprising an allowance for pavement of 3 feet outside the rails, on each side. The concrete is composed of six measures of Thames ballast to a 2-inch ring gauge, and one measure of Portland cement. The rails are laid on the foundation and duly gauged, when a 1-inch layer of fine concrete, composed of three parts of Thames ballast to a ½-inch ring gauge to one part of Portland cement, is deposited on the foundation concrete, enveloping and fixing the rails in place. At the same time the rails are filled flush at the sides with fine concrete. The excavation for this work is required to be 19 inches deep and 11 feet wide.

The work is covered in with granite paving, 7 inches deep, in 4-inch courses, bedded on the fine concrete, to finish at a level ⅛ inch above the rails. The paving is grouted with a mixture of blue Lias lime and coarse sand in the proportion of one to one, and is blinded with fine coarse ballast. The hardest sets are laid next the rails.

The following are particulars of the cost per mile, single line, of the way, laid for a width of 11 feet:—

QUANTITIES AND COST PER MILE, SINGLE LINE, OF MEAKINS WAY—SOUTH LONDON TRAMWAYS, 1880.

		£	s.	d.
Rails 112 lbs. per yard, 176 tons; tie-bars and fishes, 5½ tons; laid complete, 1,760 lineal yards	@ 26s.	2,288	0	0
Excavation, lifting and carting away, 19 inches deep, 11 feet wide, 3,406 cubic yards	,, 2s. 6d.	425	15	0
Concrete, 12 inches deep, 11 feet wide, 2,151 cubic yards	,, 13s.	1,398	3	0
Watching and lighting		30	0	0
Total for the way		4,141	18	0
Paving, 11 feet wide, 6,453 square yards .	,, 14s.	4,517	2	0
Total for the way and paving . .		£8,660	0	0

For the usual width of paving, 8 feet, for a single line, the cost for excavation and concrete is reduced by £482 0s. 6d., making the cost of the way £3,659 17s. 6d. per mile, single line; for the pavement £3,080; making together £6,739 17s. 6d.

The cost per mile of single way, as in 1892, is given by Mr. Gurdon L. Stephenson, the engineer of the tramways, as follows:—

ESTIMATE—GIRDER RAIL FOR 7-INCH PAVING, 1892.

		£	s.	d.
Rails, 112 lbs. per yard = 176 tons per mile; fishes and bolts, 12¾ tons per mile (no tie-rods): 1,760 lineal yards . .	@ 16s. 6d.	1,452	0	0
Excavation, lifting and carting away, 19 inches deep, 11 feet wide, 3,406 cubic yards	,, 3s.	510	18	0
Concrete, 12 inches deep, 11 feet wide, 2,151 cubic yards	,, 13s.	1,398	3	0
Watching and lighting		30	0	0
Total for the way		3,391	1	0
Paving, 11 feet wide, 6,453 square yards .	,, 12s.	3,871	16	0
Total for the way and paving, per mile, single line		£7,262	17	0

The Meakins rail was at best a pioneer rail, built up, as the rail-makers were not prepared with suitable machinery for rolling large rails in one piece. It was proved by experience that the old joint, shown in Fig. 39, was the weakest point of the rail. It became impossible, after a time, to keep the joints tight; and Mr. Stephenson adopted new joints, as shown in Fig. 40, made with a pair of angle fish plates, 3 feet long, riveted to the rails with six rivets, or bolted with six ¾-inch bolts and nuts, where riveting was not allowable. With these fittings, the screw-threads having been burred, the joints keep quite tight, and do not require screwing up from time to time. The whole of the

Meakins rail that was laid, about ten miles of single line, continues in use.

A portion of the way was laid on the Barker system. It is now in course of replacement by the girder rail.

In April, 1892, making together about twelve street miles, there were about four miles of the Meakins way, one mile of the Barker way, and seven miles of the girder way.

In adopting the girder rail in 1877, Mr. Stephenson, failing to get what he required in England, had recourse to the Phœnix Works at Rurhort, where he succeeded in getting rails of section No. 1, Fig. 41, rolled, which he adapted to 7-inch paving. No. 2 section he adopted for 6-inch paving.

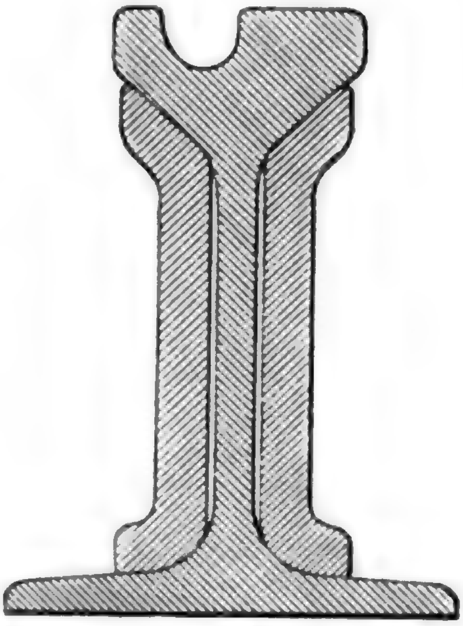


FIG. 41. South London Tramways: Section of Rail and Fish-plates. Scale $\frac{1}{4}$.

	No. 1.	No. 2.
Total height of rail . .	8 inches	7 inches
Width of base	6 ,,	6 ,,
Do. head . . .	$3\frac{1}{4}$,,	$3\frac{1}{4}$,,
Do. rolling face . .	$1\frac{5}{8}$,,	$1\frac{5}{8}$,,
Thickness of web . .	$\frac{1}{2}$,,	$\frac{7}{16}$,,
Average thickness of foot .	$\frac{1}{2}$,,	$\frac{7}{16}$,,
Weight per yard . . .	112 lbs.	90 lbs.

Unusually large fish-plates are employed for the girder rail: 2 feet in length, about $\frac{5}{8}$ inch thick, weighing 61 lbs. and 40 lbs. per pair respectively.

CHAPTER VI.

RECONSTRUCTION OF THE LIVERPOOL TRAMWAYS.

THE Liverpool Tramways were reconstructed in 1877—78, on the system of Mr. George F. Deacon, the borough engineer, who prepared the plans and specifications for the works, and under whose superintendence they were constructed. They comprised the inner circle and a section traversing Lime Street and Renshaw Street, making a total length of 3,170 yards, after having been in operation, as originally constructed, for a period of six or seven years. This renewed length cost for maintenance, in 1879, £43, or £24 per mile. The original lines then in course of reconstruction had more recently cost for maintenance from £250 to £500 per mile.

INNER CIRCLE.

The leading feature of Mr. Deacon's system, illustrated by Figs. 42 and 43, is the method of fastening the rail to the longitudinal sleeper and the foundation of concrete, by means of a central bolt. The fastening is suitable for a side-groove or a central-groove rail; but in Liverpool the central groove has been adopted. The width of exposed metal surface is thereby reduced to a minimum, whilst the whole area not occupied by the groove being utilised as a tread, the total width of tread or rolling surface is greater than that of the ordinary grooved rail.

In order at once to place the pavement and the rails on the same foundation, and to render the whole surface uniform, the streets of the inner circle have been entirely repaved, and provided with new foundations of concrete for their whole width of carriageway, simultaneously with the laying of the tramways. The old foundations of the tramways and the streets were entirely taken out, and the excavation cleared to a depth of 14¼ inches below the permanent surface of the street. On the bottom, a foundation of concrete, made with Portland cement, 7 inches deep, was laid for the whole width of the street, and finished with a smooth surface. The concrete was left alone to set and

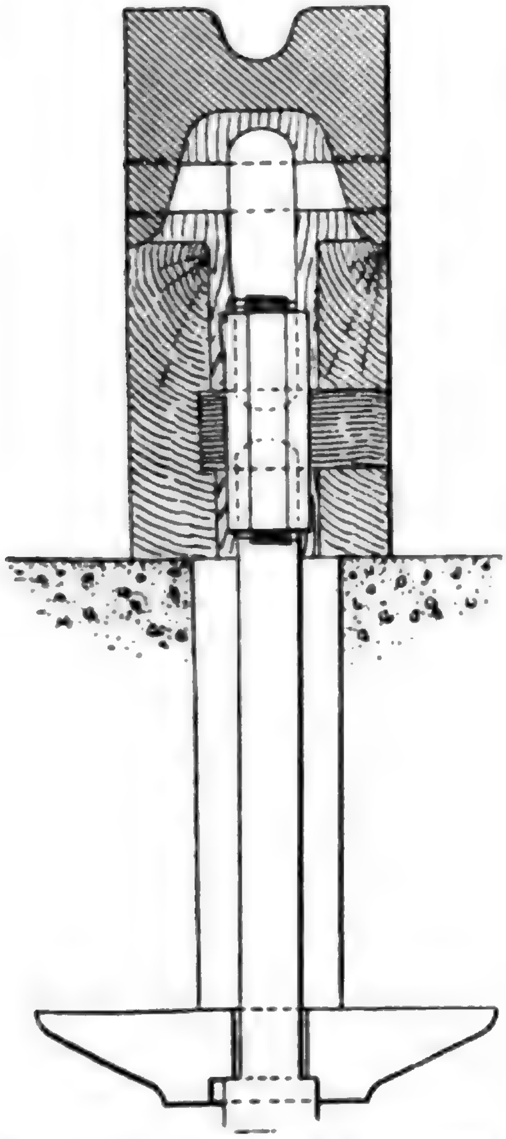


FIG. 42. Liverpool Tramways: Inner Circle Rail and Fastenings. Scale ¼.

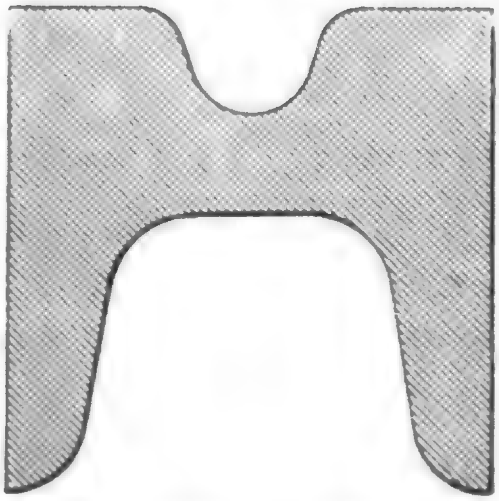


FIG. 43. Liverpool Tramways: Section of Inner Circle Rail. Scale ½.

harden, for eight days at least, before any paving was laid. The longitudinal sleepers on which the rails were laid, were of Memel, Dantzic, or Riga red pine, 5⅞ inches deep and 3¼ inches wide. For straight lengths, they were of either of two lengths, 24 feet 2 inches or 18 feet 1½ inches. For curves they were in lengths of 6 feet ¾ inch, sawn from the solid wood to the required curvature. The upper surface of the sleeper was moulded to the form of the rail. Openings were cut into the sleeper, from the upper face and one of the sides, to receive the fastenings. All the sleepers were creosoted with not less than 10 lbs. of creosote oil per cubic foot of timber. The sleepers were placed in position when the concrete became perfectly firm, and after the nuts had been placed on the holding-down bolts.

The rails are of Bessemer steel, weighing 61 lbs. per yard, rolled in lengths of 24 feet 2 inches with ten per cent. 21 feet or 17 feet in length, and making up pieces of shorter lengths. They are 3¼ inches wide and 3¼ inches deep over the flanges. The groove is in the middle of the upper surface, 1 inch wide and 11/16 inch deep, formed into a semicircle at the bottom. The upper bearing surfaces at the sides of the groove are each 1⅛ inches wide; together 2¼ inches. Some allowance, Mr. Deacon admits, must be made for defective gauging of wheels and rails; but he is of opinion that even ¾ inch is ample width of groove. The thickness of the rail, measured from the surface is 1⅜ inches. Under the groove the thickness is reduced to a half, or 11/16 inches; but, as the depth of the groove is twice as great as the depth of the wheel flanges, the rail cannot be worn at that point. The flanges depend 1⅞ inches below the head; they are of great strength, being ½ inch thick near the edges, and thickening upwards. The test applied to the rails was the fall of a weight of 20 cwt., through a height of 12 feet, upon the middle of a rail laid on supports, on a span of 5 feet. If the rail be cracked by this test, the other rails, made from the same charge, are liable to be rejected. The rails were also tested by chemical analysis. Such as were found to contain less than 0·30 per cent., or more than 0·45 per cent. of carbon, were liable to be rejected.

The rails were coated at the under side with thick coal tar, preparatory to being laid in position on the sleepers. They are fastened by means of a central ¾-inch bolt, of adjustable length, formed with an eye at the upper end, which embraces a ¾-inch round-iron cross pin, passed horizontally through ⅞-inch round holes in the flanges of the rail. The bolt passes down through the sleeper, and nearly through the stratum of concrete, and is formed with a head at the lower end, which takes a bearing upon a round cast-iron plate or washer, 6 inches in diameter, which, with the lower portion of the bolt, is imbedded in the concrete. The bolt is parted above the concrete, within the body of the sleeper, and the parted ends are united by a right-and-left-handed double nut, affording the means of solidly screwing down the rail upon the sleeper, and both together to the foundation. When the screwing down is completed, the side opening is covered by a sheet of canvas, coated with red lead. A holding-down bolt is applied at a distance of 8 inches from the end of every rail, and intermediately at intervals of about 3 feet 2 inches. The holding-down bolts are placed in position before the washers are bedded, and each bolt is enveloped in a cast-iron thimble, which is withdrawn after the concrete is set. In laying the washers, a framed template is used, from which the bolts are hung in their proper positions. The wrought iron was to be capable of bearing a tensile stress of twenty-one tons per square inch. The cast iron was to be of such strength that a bar 1 inch square, 3 feet 6 inches long, should not break with a weight less than 850 lbs. applied at the middle, on a span of 3 feet.

The paving sets are from 7 to 7¼ inches deep, laid on a ½-inch layer of sand; except the sets next the rail, which consist of the most durable stone, the hardest granite, or cross-grained trap. These are carefully hammer-dressed in such a manner that their edges touch the sides of the rails, and that they touch each other at their surfaces near the rails; so that the upper surfaces of the paving sets next the rails are practically continuous. Mr. Deacon considered that, by this means, the rate of wear and loss of level of pavement next the rails would be reduced to a minimum, and that the inconvenience of hollows or differences of level between the rails and the pavement would be obviated. The sets next the rails are bedded on cement instead of sand; they are alternately wholes and halves, and, as they are accurately gauged in all directions, they can be drawn and replaced by similar sets without disturbing the surrounding pavement. The sets are from 5 to 7 inches long, and are of such thickness that four sets, chosen at random and placed side by side, may measure not more than 14 inches across all the stones. The sets are laid as closely as is consistent with the straightness of the courses. The joints are then filled with clean dry gravel, from $\frac{3}{16}$ inch to ⅜ inch in diameter, which is shaken down by the ramming of the sets. This process is repeated until the joints are filled with gravel, and the sets no longer shake under the rammer. The joints are finally run up with a boiling mixture of pitch and creosote, by which the smallest crevice or interstice is completely occupied, and the joint is made watertight.

The whole length of the inner circle has been reconstructed and opened for traffic. The ordinary cars run upon the new line with greater ease, it has been reported, than upon the original portions of the line. As the ordinary car wheels wore out, they were replaced by central flange wheels, having a tread on each side of the flange. Until the whole of the lines were reconstructed, the central-flange wheels ran upon both the side-grooved and the central-grooved rails.

BRANCH LINES.

The general principle adopted in the construction of the inner circle of tramways, by which uniformity of foundation and of pavement was insured, and by which the rail was firmly secured to the foundation, was maintained in the modified design, Figs. 44 and 45, proposed for the branch lines, which are thus described:—

Throughout the inner circle, paving sets from 7 to 7½ inches deep have been employed; but these dimensions exceed by 1 inch the depth of paving sets generally adopted in Liverpool, for all streets except those of the very heaviest traffic. If rails of the same section as that of the rails laid on the inner circle were employed for the shallower paving, it would be difficult to reduce the depth of the sleepers by 1 inch, without unduly cutting away the sleeper at each bolt. For this reason, and also with a view to the arrangement of the fastenings, so that the rail might either be fastened down or removed without disturbing any sets, the cast-iron washers differ from those of the inner circle, in having a larger hollow to receive the head of the bolt, and having the bolt hole half an inch larger than the bolt. Before the concrete was laid, the level of the washer was fixed by a slate, placed underneath it, or by a stone, or a brick, by which the washer was supported. While the concrete was being formed above the

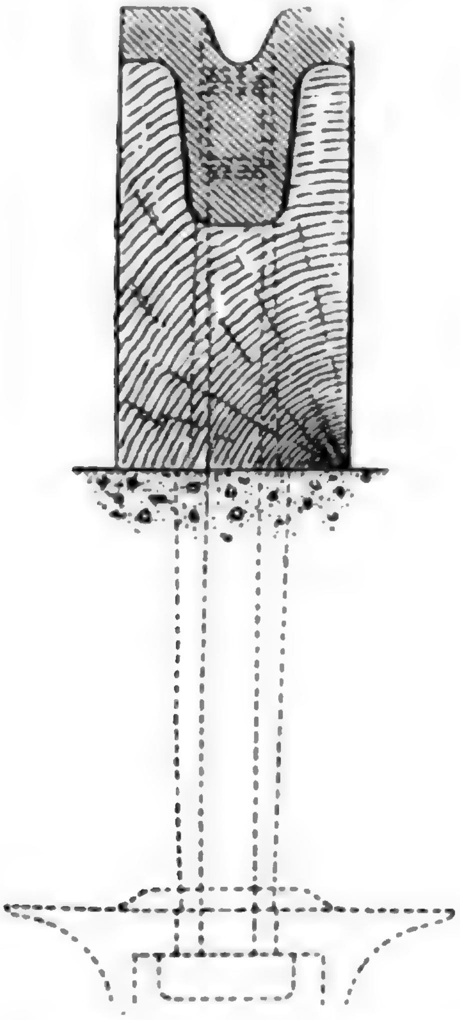


FIG. 44. Liverpool Tramways: Section of Central Grooved Rail and Fastenings. Scale ¼.

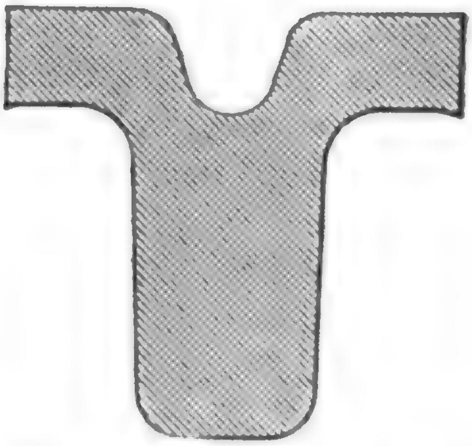


FIG. 45. Liverpool Tramways: Section of Central Grooved Rail. Scale ½.

washer, the thimble remained round the bolt, and was withdrawn when the concrete was set. The vertical holes through the sleepers, also, were half an inch larger than the bolts. The upper end of the bolt was screwed into a covered nut of phosphor bronze, which was sunk into the rail, through the bottom of the groove, and made a tight fit therein with red lead. The bolt, where it passed through the rail, was also a good fit. As the bolt was free to move in the concrete, vertically or laterally, with the rail, the joint was free from liability to dislocation by vibration or weight of traffic.

In the fastenings, shown in Fig. 44, the cast-iron washer projects upwards so that its upper side is flush with the concrete. The concrete could therefore be finished off without interference with any such projecting parts. The concrete between the jaws was afterwards scraped out, and the head of the bolt was inserted. When the sleeper was laid, a mixture of boiling pitch and creosote oil was run into the groove to fill the hole in the sleeper and the space between the jaws. This asphalte was plastic when set; and, whilst it prevented the bolt from turning, it allowed it to vibrate with the rail. The washer is rectangular in section, 3 inches long by 6 inches crosswise of the rail. With such a fastening, it is said that the tramway can be laid with facility, and as there is a liberty of 3 inches one way, and ¾ inch another way, for setting the bolt head between the jaws, no special degree of nicety is required in setting the bolt. The fastenings are now under the heaviest traffic in Liverpool.

The rail, Fig. 45, is of steel and weighs 42 lbs. per yard. It is made of the T section, having the central groove and the central web. It is 3 inches wide and 2⅞ inches deep. The nut is screwed up by means of a four-pronged key, and Mr. Deacon's experiments show that one man can readily draw down the rails with a pressure of from two to three tons at each fastening. The depth of the rail and sleeper together amounts to 6 inches, which is also the depth of the paving sets. For country or suburban lines a perfectly firm tramway may be constructed on this principle by merely laying each line of sleepers on a foundation of concrete 9 inches or 18 inches wide. In Canada, where timber is plentiful, a line of tramways has been proposed, on the principle of the line now described, without any foundations of concrete, but with longitudinal foundations, consisting of timber sleepers laid flat on their sides, to support the grooved sleepers and the rails.

It has been found in the experience that has been had hitherto of Mr. Deacon's system of fastenings, that neither cross-sleepers nor cross-ties are necessary. Under the heavy traffic of the principal streets of Liverpool the gauge has been maintained.

Although Mr. Deacon recommended the application of the central groove for tramways which are not connected with side-groove lines, yet the principle of the rails and fastenings which he has adopted may, with equal facility, be employed for the side-groove rails.

The annexed table, No. 40, contains particulars of the cost of construction of tramways on Mr. Deacon's systems, for four kinds of way, illustrated. The third and fourth are two lighter and less costly forms, on the same leading principle of construction as the second design. The rails weigh only 35 lbs. per yard, and are absolutely stronger than many rails of older forms and greater weight.

The cost of the stone pavements of Liverpool, exclusive of concrete foundation, comprising the stone sets, a layer of sand, and grouting of gravel and asphalte—is about 9s. per square yard, when the sets are 6 inches deep, and 6s. 6d. when the sets are 4 inches deep. The costs per yard forward, and per mile, two 18-inch breadths outside the rails, are as follows:—

Single line.	Per yard forward.			Per mile.		
	£	s.	d.	£	s.	d.
For sets 6 inches deep	1	2	6	1,804	0	0
Do. 4 " "	0	16	3	1,430	0	0

CROSSINGS AND POINTS.

Throughout the reconstructed lines the crossings are formed by bevelling the ends of one of the lines of rails, and cutting a groove across the other line of rails. The fixed points are of chilled cast-iron, and those which are movable have shear-steel tongues. In the ordinary side-grooved points the tread of the wheel travels for some distance only on the thin edge of the point, and so rapidly wears it down. When the point is thus worn the wheel sinks and runs below the level of the rail; and, in passing over the point from the branch to the main line, it has to remount on the main line rail, an operation by which an inclined plane is gradually worn into the surface of the rail. This evil, it is thought, is to a great extent obviated by the use of the central flanged wheels employed to run upon Mr. Deacon's rails, for one of the treads of the wheel has always a bearing upon the tread of the rail. In order still further to increase the width of bearing surface, the width of the groove at or near the point is reduced as much as is practicable; and the wheel, in running over the point from the branch line, arrives in a much shorter distance upon the tread of the main-line rail. With the same object in view—the preservation of continuity of bearing surface—the depth of the groove at and near the joint is made the same as the projection of the wheel flange.

For the subsequent work of reconstruction or renewals, under the direction of Mr. Clement Dunscombe, the city engineer, Mr. Deacon's system was adopted by him, subject to modifications with respect to the fastenings and the employment of sleepers of cast-iron. In a report to the City Council Mr. Duncombe laid down the leading conditions for the best system of tramway as follows :—

1. The rail and sleeper are fastened down to the concrete foundations by means of suitable fastenings.

2. The sleepers are practically continuous.

3. The rail can be replaced or tightened up without disturbing the paving.

4. The sleepers present a true vertical face, free from all projections, so as to admit of close paving on each side of the rail.

On a solid foundation, with durable pavement, of which the sets next the rails are specially dressed and accurately gauged, such a system, he adds, possesses all the elements for a good tramway. Whilst the inner circle was laid with Mr. Deacon's **H** rail, as it may be called, with fastenings worked from the side

TABLE NO. 40.—LIVERPOOL TRAMWAYS:—DEACON'S TRAMWAYS, WITH COMPENSATING FASTENING.

Quantities and approximate cost per yard forward, single line (exclusive of paving).

Description of material or work.	No. 1. Tramway as relaid in Inner Circle, Liverpool. Foundation of concrete, 8 ft. wide. Rail, 61 lbs. per yd.		No. 2. Tramway proposed for urban branch lines, Liverpool. Foundation of concrete, 8 ft wide. Rail, 43 lbs. per yd.		No. 3. Same as No. 2, with foundation of concrete, 12 in. wide under each sleeper. Rail, 35 lbs. per yd.		No. 4. Same as No. 3, with cross timber sleepers at average intervals of 3½ ft., instead of concrete. Rail, 35 lbs. per yd.	
	cwt. qr. lb. oz	£ s. d.	qr. lb. oz.	£ s. d.	qr. lb. oz.	£ s. d.	qr. lb. oz	£ s. d.
Bessemer steel rails .	1 0 10 0	0 8 8	3 2 0	0 6 2	2 14 0	0 4 10	2 14 0	0 4 10
Wrought-iron screwed bolts, nuts and pins	0 0 6 8	0 1 5	0 2 10 (no nut or pin)	0 0 7	0 2 10 (no nut or pin)	0 0 7	0 1 15¼	0 0 6
Two cast-iron washers	0 0 10 8	0 0 8	0 14 0	0 0 10	0 14 0	0 0 10	0 5 7⅜	0 0 4
Two solid-ended Phosphor bronze nuts (screwed)	None.	0 0 0	0 0 6½	0 1 0	0 0 5	0 0 9	0 0 5	0 0 9
Holes drilled in rails	2 holes.	0 0 4	4 holes.	0 1 0	4 holes.	0 1 0	4 holes.	0 1 0
Baltic red-pine sleepers, seasoned, shaped, and creosoted; two lineal yds.	6 in. × 3¼ = ·81 cubic ft.	0 2 10	5½" × 3" = ·683 cubic ft.	0 2 8	5½" × 3" = ·688 cubic ft.	0 2 8	5½" × 3" = ·688 cubic ft.	0 2 8
Drilling and cutting holes for fastening in sleepers	..	0 0 8	..	0 0 3	..	0 0 3	..	0 0 3
Foundation .	P. cemt. concrete 7½" deep, 2⅔ sq. yds.	0 11 0	P. cemt. concrete 5" deep, 2⅔ sq. yds.	0 7 6	P. cemt. concrete 6" deep, ⅔ sq. yds.	0 2 3	2 lin. yds. ross sleepers	0 2 7
Excavation . .	..	0 3 4	..	0 2 6	..	0 2 0	..	0 2 0
Labour in laying rails and sleepers	..	0 2 0	..	0 1 1	..	0 1 1	..	0 1 3
		£ s. d.		£ s. d.		£ s. d.		£ s. d.
Cost per lineal yard, (exclusive of paving)	..	1 10 11	..	1 3 7	..	0 16 3	..	0 16 2
Cost per mile (ditto).	..	2721 0 0	..	2076 0 0	..	1430 0 0	..	1423 0 0

NOTE TO TABLE.—The cost for paving, in sets 6 inches deep, comprising the 18-inch breadths outside the rails, is £1 2s. 6d. per yard forward, or £1,804 per mile.

(see Fig. 42), an experimental length of 12 yards of single line, of the T section, "the central grooved rail," fixed by "jaw washers," was laid in Lord Street, at its junction with South John Street, in November, 1877, and has been in use since that time. At this point the heaviest cross-traffic over the tramway exists, exceeding 2½ millions of tons per annum, besides an exceptionally large longitudinal traffic, in which loads of seven tons, on four-wheeled trucks, are common, with occasional loads of 12 tons.* On January 15, 1881, a rail of each kind of way was taken up at the given place in Lord Street, and the condition of the rails, sleepers, and fastenings, after three years' work, was found satisfactory. During that interval, all that was required to maintain the rolling surface in good condition was the occasional tightening of the rails, especially at the joints. Mr. Dunscombe hence concluded that rails—the T rails—which could be tightened or replaced from the surface, were preferable to those—the H rails—which necessitated the removal of the pavement in order to gain access to the fastenings. For this reason he selected the T section for further construction; and also as affording the maximum degree of strength, in combination with the minimum quantity of metal. He also adopted continuous sleepers of cast iron, of special design, in preference to timber sleepers, in order to insure a valuable asset, as a perfect substructure, when the lease of the tramways to the Tramway Company shall expire on December 31st, 1896. The general design and construction are shown in Figs. 46, 47, 48, and 49.

The specification for the reconstruction and extension of the Liverpool Tramways provided that the existing carriage ways were to be excavated to a depth averaging 14½ inches below the finished surface, for the Whitechapel and the Pierhead routes, and 12½ inches for the remaining routes. Beds of concrete were to be laid respectively 7 inches and 6 inches deep, and carefully floated to the contour. The concrete was to be composed of

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* See Mr. G. F. Deacon's paper on "Street Carriage-way Pavements," in the *Minutes of Proceedings of the Institution of Civil Engineers*, 1879, vol. lviii., p. 1, for an instructive notice of the street traffic of Liverpool.

5 parts by measure of perfectly clean river or sea gravel, 5 parts of broken hard stones, and 1 part of Portland cement. The cement was to bear successfully the following tests:—

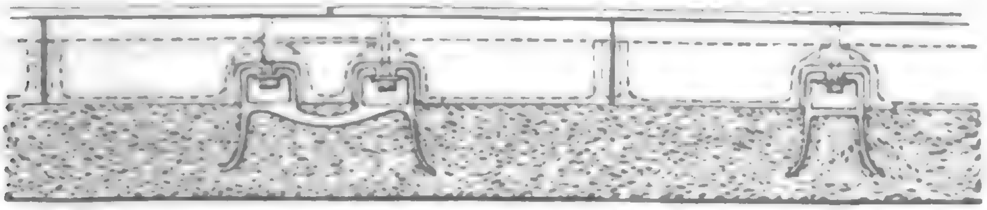


FIG. 46. Deacon's Way, as laid by Mr. Dunscombe, Liverpool. Scale $\frac{1}{24}$.

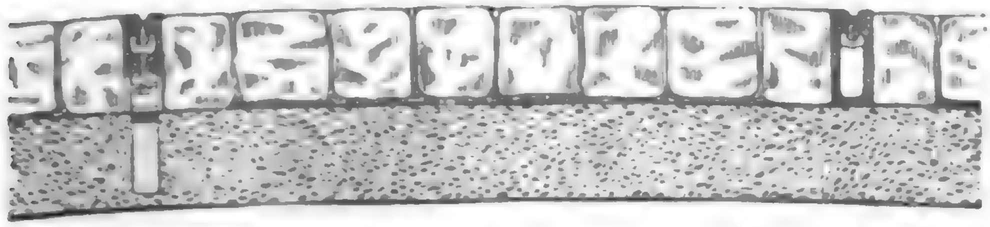


FIG. 47. Deacon's Way, as laid by Mr. Dunscombe, Liverpool. Scale $\frac{1}{24}$.

1. It is not to leave a residue exceeding ten per cent. when sifted through a No. 50 gauge wire sieve.

2. Samples gauged with water are, within twenty-four hours, to be immersed in still water, until they are seven days old, when they are to resist a tensile stress of at least 800 lbs. on the sectional area of 2¼ square inches.

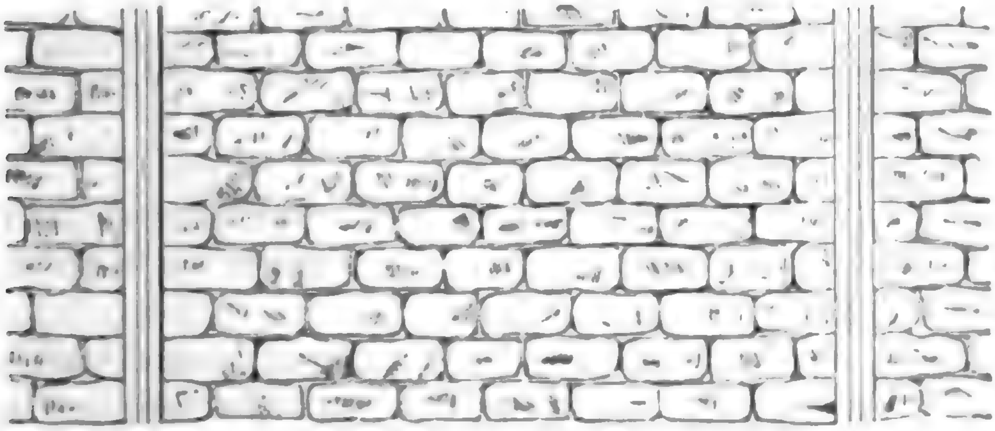


FIG. 48. Deacon's Way, as laid by Mr. Dunscombe, Liverpool.—Paving. Scale $\frac{1}{24}$.

3. Slow-setting cement is not to be firm within three hours, and quick-setting cement is to be firm within half an hour. The test for firmness is that of resistance to the finger nail.

On consolidated bottoms—hard-pitched or otherwise—a bed of bituminous concrete may be laid instead of cement concrete. Clean, dry, hard, broken stone, or foundry slag, in pieces not larger than 3 inches, is to be laid, and well rolled and filled up with boiled pitch and creosote oil. The surface is to be covered with fine broken stone or gravel, and well rolled. Where the depth is insufficient for holding down the rail, the ground below the rail is to be removed for a width of 9 inches on each side of the rail, to the requisite depth, and the space is to be filled with concrete.

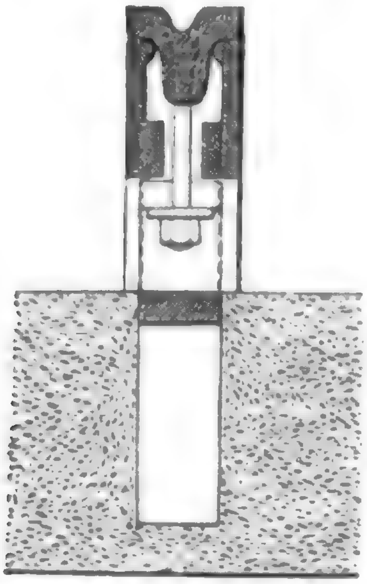


FIG. 49. Deacon's Way, as laid by Mr. Dunscombe, Liverpool. Section of Rail, Sleeper, and Jaw. Scale ⅛.

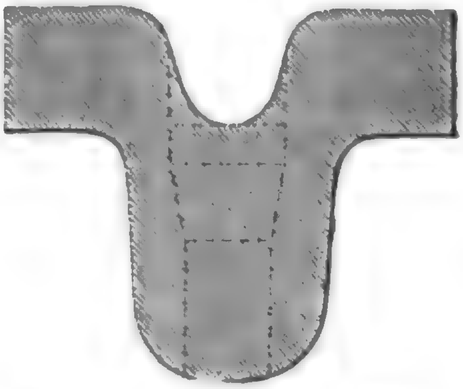


FIG. 50. Deacon's Rail, Liverpool. Scale ½.

The paving for the whole width extending 18 inches outside the rails, is to be of granite or syenite sets, 7½ inches deep, 3½ inches wide, and from 5 to 8 inches in length, for the Whitechapel and Pierhead routes; for the remaining routes, 6½ inches deep, 3½ inches wide, and from 5 to 7 inches long. To be laid on a ½-inch layer of fine gravel. The sets of syenite, next the rails, are to be finely dressed at the sides abutting the rails, so as to touch them approximately at all points; the upper edge is to touch the rail for its entire width, and the base of the set is to bear, at its extreme ends, on the bedding. The sets next the rail are to be gauged so that they touch in the joints at right angles to the rail for a length of at least 2 inches from the rail.

The rails are of Bessemer steel, weighing 40 lbs. per yard, of T section, Fig. 50, with a central groove, 1 inch wide, and treads each 1 inch wide and ⅞ inch thick, making a total width of 3 inches. The rail is 2¼ inches in depth, and the web or body of the rail is 1¼ inches thick at the lower part. The length of ordinary rails are to be 27 feet 8¾ inches and 21 feet 8¾ inches. But a proportion of the whole quantity of rails, not exceeding seven per cent., are to be 24 feet 8¾ inches, 18 feet 8¾ inches, and 15 feet 8¾ inches in length. Curved rails are to be bent while hot to true curves. The rail is drilled vertically for the holding-down bolts, at distances of three feet between the centres of the holes; except at the ends, where the centres of the terminal holes are 4⅜ inches from the ends of the rail.

The limits of the composition of the steel are to be as follows:—

Phosphorus, not above	·10	per cent.
Carbon from ·25 to ·45, average . .	·35	,,
Manganese, not exceeding . . .	1·00	,,

There is not to be any more silica in the steel than is necessary for working it.

The rails are tested chemically for the percentages of carbon, phosphorus, manganese, silica, &c. For this purpose, examples are taken from each converter charge, consisting of 2 ounces of borings. The mechanical tests and the results of the tests are as follows:—

1. The drop test: a weight of 20 cwt. to fall from a height of 10 feet upon the centre of a rail supported on bearings 3 feet apart, without fracture. The average deflection for twenty-two tests of pieces of rail, consisting of crop ends from 4½ feet to 5½ feet in length, was for nine drilled rails, 9½ inches, and for twenty undrilled rails, 8¾ inches. In this case the holes for the drilled rails were placed directly on the bearings.

2. Tensile test: pieces cut from rails to have a tensile strength of from 28 to 31 tons per square inch, with an elongation of 20

per cent. in a length of 6¼ inches. The average breaking weight for three tests was 28¼ tons per square inch, and the elongation 20 per cent.

3. Hot bending tests: strips heated to a cherry-red heat to bend double round a curve of which the diameter shall not exceed three times the thickness of the piece tested. Results of three tests satisfactory.

4. Cold bending tests: samples of rails to be bent double when cold, to a radius of 6 inches, having the groove inside the curve. Results of two tests satisfactory.

5. Deflection test: rails supported upon bearings 3 feet apart, and loaded at the centre, to have an elastic limit of 7 tons of load. For seven tests the greatest elastic limit was 10 tons, the least 5 tons (rejected); the average, 7¼ tons.

In another series of tests, designed to ascertain the difference of deflection when a drilled hole was placed at the middle of the space between the supports, the following results of tests were obtained:—with 1st, a drilled rail 10 feet long, the drilled holes being placed on the supports; 2nd, another part of the same rail as No. 1, having a drilled hole at the centre between the supports; 3rd, the first experiment repeated with a piece of another rail 10 feet long; 4th, with a piece of the same rail, the second experiment repeated. The loads were applied gradually by means of a steam lever machine, at the middle, between the supports:—

Load.		1st rail.		2nd rail.		3rd rail.		4th rail.	
Tons.		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
5	Deflection . .	$\frac{5}{32}$	. .	$\frac{3}{16}$	. .	$\frac{5}{32}$	. .	$\frac{1}{8}$	. .
	Permanent set .	. .	0	. .	0	. .	0	. .	$\frac{1}{32}$
6	Deflection . .	$\frac{3}{16}$	. .	$\frac{3}{16}$	. .	$\frac{3}{16}$	. .	$\frac{3}{16}$	. .
	Permanent set .	. .	0	. .	0	.	0	. .	$\frac{1}{32}$
7	Deflection . .	$\frac{1}{4}$	. .	$\frac{1}{4}$	. .	$\frac{1}{4}$	. .	$\frac{3}{8}$	. .
	Permanent set .	. .	0	. .	$\frac{1}{32}$	. .	0	. .	$\frac{9}{64}$
8	Deflection . .	$\frac{9}{32}$	. .	broke	. .	$\frac{5}{16}$	. .	. .	. .
	Permanent set .	. .	$\frac{1}{64}$	. .	. .	. .	$\frac{1}{16}$	. .	. .
9	Deflection . .	$\frac{5}{16}$	. .	. .	. .	$\frac{5}{8}$	. .	. .	. .
	Permanent set .	. .	$\frac{3}{32}$	. .	. .	. .	$\frac{3}{8}$	. .	. .

These results show that the stiffness of rails within their elastic ranges was not materially affected by the presence of drilled holes. Two pieces of rail, ⅝ inch square, tested for tensile strength, broke each with a load of 19¾ tons, equivalent to 50 tons per square inch, with an elongation of 16 per cent. in 6¼ inches.

The sleepers are of tough cast iron, containing not less than one-sixth of good foundry scrap. They weigh 90 lbs. per yard, and are of a trough-like section. They are 5 feet 11⅝ inches in length, except at junctions, where they are 3 feet 8⅝ inches long, and at curves 2 feet 11⅝ inches. They are made with transverse ribs, and the recesses are overarched, within the casting. They are filled to the level of the under side of the rail with Portland-cement concrete; and the recesses are protected by a coating of Dr. Angus Smith's solution—pitch and creosote oil—while heated to a temperature of 320° Fahr.

Special sleepers are laid at the ends of the points, and elsewhere where required. Besides giving a bearing for the rails they occupy the angular space formed at the points, where they are roughened at the surface. They are 3 feet in length and are cast of the best cold-blast iron, chilled for a depth of at least ¾ inch.

The points are 9 feet long, and are either fixed or movable. Fixed points are laid where the traffic is in one direction only, and also on trailing points. They are of cold-blast iron and chilled. Movable points are laid for branches, having a movable tongue of tough cast steel, pinned to the stock by means of a cylinder-conical-headed bolt and nut of phosphor bronze, and controlled at the other end by means of a steel pin, passed through the point. Both the steel switch and its bed are planed. The point castings are 3 inches wide at the narrow end, and 6 inches at the broad end; cast hollow, and filled with Portland cement concrete flush with their lower sides.

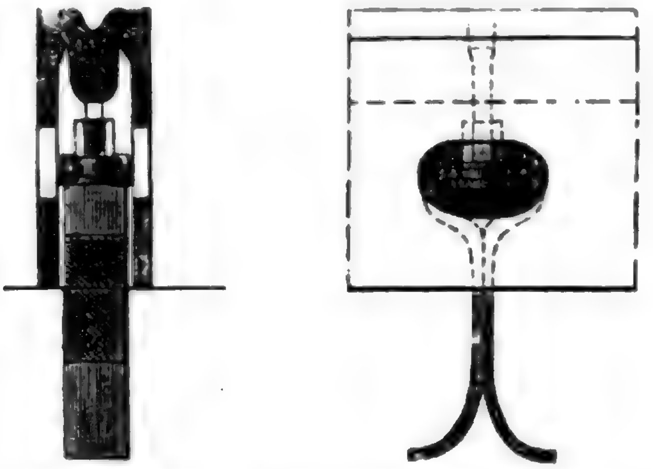
Crossings are of cold-blast iron, made with sleepers for the two rails at each end, with solid angular spaces roughened. The exposed surfaces are chilled. The crossings are cast hollow and filled with concrete.

For the cast-iron sleepers, test-bars 1 inch square and 42 inches long, are to support a load of not less than 800 lbs. placed midway between supports 3 feet apart For the points and crossings, like test-bars are to support not less than 850 lbs. at the centre for a clear interval of five minutes. Of 340 test-bars for sleepers, the transverse resistance was from 804 lbs. to 1,150 lbs.; and averaged 845 lbs.; and the deflection was from $\frac{5}{8}$ inch to 1½ inches, averaging $\frac{13}{16}$ inch. Of 55 test bars for points and crossings, the transverse resistance was from 950 lbs. to 1,220 lbs. and averaged 986 lbs.

The rails are fastened to the sleepers by means of cylinder conical-headed No. 6 phosphor bronze $\frac{9}{16}$ inch bolts, and wrought iron collar nuts. The bolts, coated with red lead, are passed through holes drilled to gauge centrally through the rails and through holes drilled in the upper part of cast-iron holding-down jaws, which are solidly embedded in the foundation of concrete. The collar nuts, of the best rivet iron, take a bearing within the jaws; and, when screwed up, they pull down the rail and sleeper together to the foundation. To preserve them from oxidation the recess in which they are lodged is filled with plastic pitch. By means of the slot or groove cut across the head of the bolt, it may afterwards be tightened up with a suitable driver from the surface; and while the nut is held firmly in its plastic envelope, the envelope is sufficiently elastic to admit of slight compensatory movements of the bolt from above, under heavy traffic from above. The bolts are screwed with twelve threads to an inch.

The bolts and nuts were then tested, to the extent of 1 per cent. of samples, by screwing the nuts home, suspending the bolts by their necks in a closely fitting socket, and hanging a load of 3 tons from the nut for fifteen minutes. During this interval the bolt was turned once round in the nut as often as might be required. After the bolt was released and unscrewed, if any indications were visible of stripping of the thread of either the bolt or the nut, or of the collapse of the neck of the bolt, or of any other defect, the fastenings were rejected. Fifteen bolts out of 385 thus tested were broken.

The test load of 3 tons for the bolts and nuts was determined by the following process:—An experimental ⅝-inch wrought-iron bolt, screwed with 14 threads to the inch, and cupheaded, was suspended by a cylindrical gun-metal nut, 1 inch in diameter and 1¼ inches in length, from a horizontal bar. The nut was turned round from the top by means of a cross-headed key, of which the head was 16 inches long, by a strong workman. On the cup head, at the lower end, a circular disc was placed, loaded with heavy weights until the workman became unable to turn the nut from the top by means of the key. The limiting weight was found to be 2¾ tons nearly. The test load was therefore fixed at 3 tons: a greater strain than would ever, in practice, be put upon the fastenings.



FIGS. 51 and 52. Deacon's Way, Liverpool. Alternative Fastening. Scale ⅙.

A proposed modification of the fastenings now employed is shown in Figs. 51 and 52. The bolt is reduced from 6½ inches to 2½ inches in length, and is fitted with a wrought-iron socket bolt, with a nut and collar head.

The way is laid as follows:—On the floor of the excavation 6-inch cubes of concrete are laid at intervals and levelled for the support of the sleepers. The rails are laid on the sleepers, the bolts are inserted, and jaws are attached. A washer ¼ inch thick is temporarily inserted between the top of the jaw and the crown of the arch in the sleeper. The rails having been placed to gauge, the foundation of concrete is laid in; well packed under the sleepers by means of steel rammers. When the concrete has set, the bolts are withdrawn, that the temporary washers may be removed, and replaced and screwed up from above. The rails are thus drawn down to the foundation, under a pressure estimated at 3 tons for each bolt, the recesses are then filled with plastic pitch, and the work is ready for the paving.

The contract prices (April, 1881) for material delivered upon the respective works, and upon which the nett cost of the Liverpool tramways has been based, were as follows:—

	£	s.	d.	
Bessemer steel rails	8	15	0	per ton.
Castings, straight	5	14	0	,,
curved	6	0	0	,,
Holding-down jaws, &c.	5	14	0	,,
Special sleepers, points and crossings (cold-blast iron) chilled on exposed surface, inclusive of all patterns	9	5	0	,,
Collar-headed nuts	2	8	0	per cwt.
Phosphor-bronze bolts	9	17	6	,,
Syenite sets, 3¼ inches wide, 6¼ inches deep, and 5 to 7 inches long	1	9	0	per ton.
Do. per square yard, as laid	0	8	8	,,
Broken stone for concrete	0	5	6	,,
Do. per cubic yard of concrete	0	4	9	,,
Portland cement (Corporation standard)	1	19	6	,,
Do. per cubic yard of concrete	0	5	9	,,
Dee gravel	0	5	6	,,
Do. per cubic yard of concrete	0	5	9	,,
Shingle for filling joints of paving	0	6	6	,,
Do. per square yard of paving	0	0	1½	,,
Pitch	1	6	6	,,
Creosote oil	0	0	2¾	per gal.

Wages:—

Ordinary platelayers	0	4	0	per day.
Leading	0	5	0	,,
Foremen	7s. 6d and 8s. 6d.			,,
Labourers	0	3	10	,,

Wages—*continued.*

Paviors (outside tramway limits) piece-work* 6½d. per square yard.

Do. (inside do.) 9d. per square yard.

Masons . . . . 0 5 6 per day.

Set dressers, day-work . . . . . . 0 6 0 „

Do. piece-work. Various prices which are regulated according to special class of sets required, and vary from 7s. 6d. to 16s. per ton.

QUANTITIES AND COSTS (CONTRACT PRICES) PER MILE, SINGLE LINE, OF DEACON'S SYSTEM, AS LAID BY MR. DUNSCOMBE IN RECONSTRUCTION AND EXTENSION, LIVERPOOL CORPORATION TRAMWAYS, 1880—81.

		£	s.	d.	£	s.	d.
Bessemer steel rails, drilled complete, 40 lbs. per yard, 62·85 tons . .	@	8	15	0	550	0	0
Cast-iron sleepers, covered with non-corrosive covering complete, 90 lbs. per yard, 141·42 yards . . .	,,	5	14	0	806	2	0
Cast-iron holding-down jaws, do. 16·50 tons	,,	5	14	0	94	1	0
Phosphor bronze bolts, 13¾ cwt. . .	,,	9	10	0	130	12	6
Wrought-iron nuts, 18⅔ cwt. . .	,,	2	8	0	44	16	0
Excavation, 12½ inches deep, including carting and tipping, 1,825 cubic yds.	,,	0	4	2	380	4	1
Portland cement concrete, 7 inches deep, including labour of mixing and spreading, and finishing to an even surface, for paving, 988½ cubic yds.	,,	0	18	6	914	7	0
Laying, comprising all labour and materials for filling sleepers with concrete, filling recesses with pitch; and all platelaying in connection with jaws, sleepers, rails, and fastenings, 1,760 lineal yards . . .	,,	0	1	6	132	0	0
					3,052	2	7
Paving; syenite set paving, 3¼ inches by 6¼ inches, including all labour and materials, 4,400 square yards .	,,	0	11	2	2,456	0	0
Total for way and paving . . .					£5,508	2	7

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* These prices include all labour from the formation of the upper surface of the concrete.

A tramway similar in construction, for light traffic on suburban lines, was designed by Mr. Dunscombe, with Bessemer steel rails of 30 lbs. per yard, and cast-iron sleepers of 60 lbs. per yard :—

Per mile, single line.

		£	s.	d.	£	s.	d.
Rails, 47·15 tons	@	8	15	0	412	0	0
Sleepers, 94·29 tons	,,	5	14	0	537	7	7
Jaws, 11·00 tons	,,	5	14	0	62	14	0
Bolts, 6·87 cwt.	,,	9	10	0	65	6	3
Nuts, 23·60 cwt.	,,	2	8	0	47	2	10
Laying 1,760 lineal yards	,,	0	1	3	110	0	0
					1,234	10	8
Foundation and paving					2,200	0	0
Total for way and paving					£3,434	10	8

The comparative cost of timber sleepers and cast-iron sleepers may thus be stated :—

	Per lineal yard, single line. s.	d.	Per lineal mile. £	s.	d.
Sleepers of cast iron, 90 lbs. per lineal yard, @ £5 14s. per ton	9	2	806	13	4
Sleepers of best Baltic red pine, 6 inches by 3 inches, shaped to pattern, and creosoted, @ 5s. 6d. per cubic foot	4	1½	363	0	0
Difference in favour of timber sleepers per lineal mile			£443	13	4

The experience for the last ten years (1892) of the Lyver system of tramways as laid in Liverpool appears to show that the economy of maintenance anticipated by the inventors has been justified. During the decade the traffic has been enormous; and the wear and tear of the lines is materially influenced by the traffic ever flowing to and from the docks.

On the basis of 100,000 tons of trafic per annum on one rail, the wear has been about ·015 inch, equal to ·0086 of the original weight: 40 lbs. per lineal yard. Of course the rails have varied in their wear according to the particular conditions of their locality.

The cost of maintenance over the 47½ miles was under 1 per cent. per annum, on the basis of a cost of £6,000 per mile. This price is for a first-class permanent way on concrete foundations into which the rails are secured.

A lighter and cheaper form has been designed for and successfully used in country places where there is no concrete bottom or foundation, or where the employment of concrete is to be reduced to a minimum. In this case, the rail is secured to a troughed girder sleeper, and the cost of a 10-lb. steel rail, sleeper, and fastening would not exceed £1,500 per mile.

Another modification of the Lyver system consists in its application to dock railways on which locomotives are used.

The advantages of a channeled rail in towns instead of the ordinary form of railway track is obvious as regards its non-interruption of ordinary traffic, non-disturbance of road level, and ability to relay without disturbing the roadway. Too great stress cannot, it is thought, be laid on the last point.

CHAPTER VII.

DUBLIN TRAMWAYS.

THE superiority of the Larsen rail—as a rail with side fastenings—to the rails with vertical spike fastenings, was established by the experience acquired of its capabilities on the London Street Tramways, though in these, as in the Belfast tramways, subsequently constructed, the system of side fastening was but imperfectly developed. Mr. Hopkins improved the system of the side fastener by substituting for the fastener in two or three pieces, a solid staple, or "dog," in one piece, which he employed in the construction of the Dublin tramways, of which he was the engineer, and the works for which were commenced in October, 1871. The design of the tramway was very simple: four rails laid on four longitudinal sleepers, bedded in four longitudinal trenches of concrete; similar to the first system adopted by Mr. Hopkins for tramways in London. The rail, shown in section, Fig. 53, weighed 53 lbs. per yard; it is 4 inches wide; but though it is thinner than the grooved rail of earlier design it is deeper, and shows clearly a better distribution of material than in these rails; better even than the Belfast rail, which was of later construction, and designed by Mr. Larsen. The rolling surface of the Dublin rail is 2 inches wide; the groove is 1⅛ inches wide and 11/16 inch deep, with a flat floor;

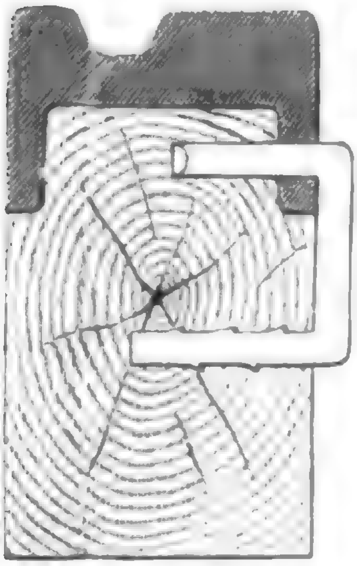


FIG. 53. Dublin Tramways:—Section of rail and sleeper, showing the staple fastening. Scale ¼.

the ledge is $\frac{7}{8}$ inch thick at the surface. The rails were fixed upon longitudinal fir sleepers 4 inches wide and 6 inches deep, in lengths of from 18 to 25 feet, and rebated to receive the rails. The rails were pressed down and solidly bedded by means of screw-cramps. In this position they were fixed to the sleepers by means of staples in one piece, made of $\frac{1}{2}$-inch round iron, the lower ends of which were barbed. A section of the rail and sleeper thus fixed together is shown in Fig. 53. The staples were applied at intervals of 3 feet on each side of every rail, and there was one on each side of the rail at a distance of about 4 inches from each end. At curves in the line, if not severe, the sleepers were in some instances sawn half through the outer side at intervals, and wedges were driven into the cuts until the sleeper took the required curvature. At sharp curves, the sleepers in short lengths were sawn to the required curvature. The ends of the rails were stayed with wrought-iron plates, 7 inches long, $\frac{5}{16}$ inch thick, and $2\frac{1}{2}$ inches wide, let into recesses adzed off the sleeper. The intention in applying these plates was to maintain the ends of the rails at the same level.

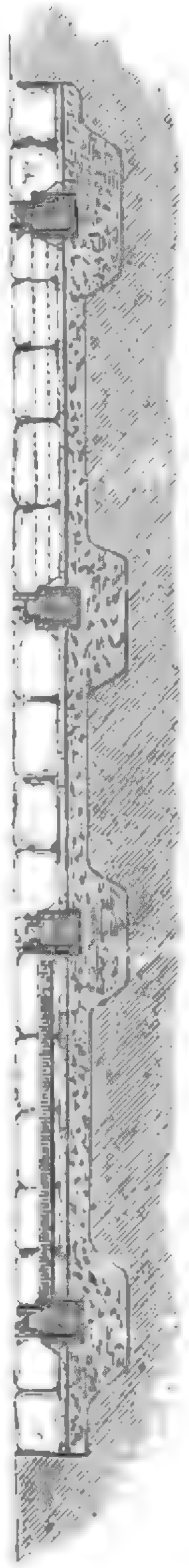


FIG. 54. Dublin Tramways:—Section of the double way. Scale, $\frac{1}{16}$.

A general section of both lines for a double way is given in Fig. 54. The rails of each line are placed to a gauge of 5 feet 3 inches, which is the railway gauge of Ireland, though railway waggons cannot be run on the tramway. There is a clear 4-foot space between the two lines of way, and there are the customary 18-inch breadths outside the outer rails. The working edge of the groove is at the middle of the width of the rail, or two inches from each edge; and the total width of roadway occupied by the double line of tramways is made up as follows:—

	Ft.	In.
Two lines, 5 feet 3 inches gauge	10	6
Intermediate space	4	0
Four half-widths of rail	0	8
Two breadths of paving outside	3	0
Total	18	2

making a total width of 18 feet 2 inches. Four trenches were cut in the tracks of the rails, to a depth of 18 inches below the level of the roadway, to a width averaging about 2 feet, whilst the intervening surface was excavated to a depth of 11 inches. The excavated space was filled with concrete to a level of about 7½ inches below the surface, forming a level bed for the sleepers. The concrete was made with blue lias lime, or with Portland cement. The ends of the sleepers were laid in cast-iron chairs, like those of the Liverpool line, page 20, which fitted them tightly and were fixed to them at the outer side by two nails, one to each end of the sleeper. The inner sides were formed with dovetail and slots, to receive the ends of a tie-bar at each point. Intermediate ties of flat iron were placed at intervals of about seven feet; they were split at the ends, and formed with right and left knees in the manner shown in Fig. 51, page 157, by which they were nailed or spiked to the sleepers. A bed of sand 1 inch thick was laid on the concrete to receive the paving, which consisted of granite sets, 6 inches deep. The transverse joints of the paving, 1 inch wide, were filled with small gravel or shingle, which was rammed into the joints, after which the paving was beaten with ordinary rammers.

The following is a statement of the quantities with the approximate actual cost, for one mile of double way:—

DUBLIN TRAMWAYS—QUANTITIES AND APPROXIMATE COST FOR ONE MILE OF DOUBLE WAY, 1871—72.

			£	s.	d.
Excavation	3,500 cubic yards	@ 2s.	350	0	0
Concrete	1,400 ,,	,, 6s.	420	0	0
Carried forward			£770	0	0

DUBLIN TRAMWAYS—*continued.*

			£	s.	d.
Brought forward			770	0	0
Sand and shingle	400 tons	@ 3s.	60	0	0
Sleepers	3,520 cubic feet	,, 2s. 6d.	440	0	0
Rails, wrought iron	7,040 lineal yards 190 tons	,, £12	2,280	0	0
Chairs, cast iron	8¼ tons	,, £8	66	0	0
Nails	½ ,,	,, £24	12	0	0
Cushions	0·60 ,,	,, £10	6	0	0
Staples, 14,080 at 350 lbs. per 1,000	2⅕ ,,	,, £26	57	4	0
Tie-bars	11 ,,	,, £16	176	0	0
Laying rails, single line	3,520 lineal yards	,, 1s.	176	0	0
Cost of way			4,043	4	0
Paving	9,973 square yards	@ 5s. 6d.	2,742	11	6
Carting away débris			50	0	0
Watching and lighting			120	0	0
Management and contingencies			150	0	0
Total approximate cost per mile of double way			7,105	15	6
Do. do. single way			3,552	17	9

The first portion of the lines was opened between St. Stephen's Green and Rathgar, 2¼ miles, on February 1, 1872. The tramways were fully opened to a length of 16 miles early in 1874.

CHAPTER VIII.

GLASGOW CORPORATION TRAMWAYS, 1870—73.

An Act of Parliament was passed in 1870 for the construction of the Glasgow Street Tramways by a private company. The powers conferred by the Act were, in the same year, transferred to the Corporation of Glasgow, by whom, accordingly, the tramways of Glasgow have been constructed.

In designing the first tramway, the engineers, Messrs. Johnstones & Rankine, developed the employment of the transverse sleeper for giving bearing surface and for strength. They adopted a modified form of the old flat-grooved rail in combination with longitudinal and transverse sleepers and bituminous concrete, and produced a structure which surpassed all others that had previously been laid for tramways, for strength and solidity. The system of construction is illustrated by Fig. 55. It was adopted for the first contract, which was entered into in 1871. The first portion of the line under the contract was 2 miles 300 yards, and was opened in August, 1872. By the end of the year 1872, 9 miles of tramway were completed and opened, and the whole of the tramways executed under the first contract, passing over 9$\frac{3}{4}$ miles of streets, were completed in June, 1873.

In designing the rail a single broad fillet, on the lower side, under the groove, was substituted for the pair of lateral fillets employed in other rails made at that time. The fillet was let into the longitudinal sleepers, and, besides providing the needful lateral resistance at either side, it aided in strengthening the rail at the weakest part of the section—under the groove—whilst it afforded a deeper bearing for the countersunk heads of the vertical bolts employed for fixing the rail to the sleeper. The longitudinal sleepers rested in cast-iron chairs, formed with broad soles, spiked to transverse wood sleepers laid in concrete. The bolt, having a slotted head, was screwed into a nut with a washer at the underside of the longitudinal sleeper, and a hasp was applied to prevent the nut from turning when the bolt was required to be tightened up. But the hasp was abandoned after the construction of the first section.

The works under this contract were as follows, for double way, except 1,110 yards, or about two-thirds of a mile, which was single way:—

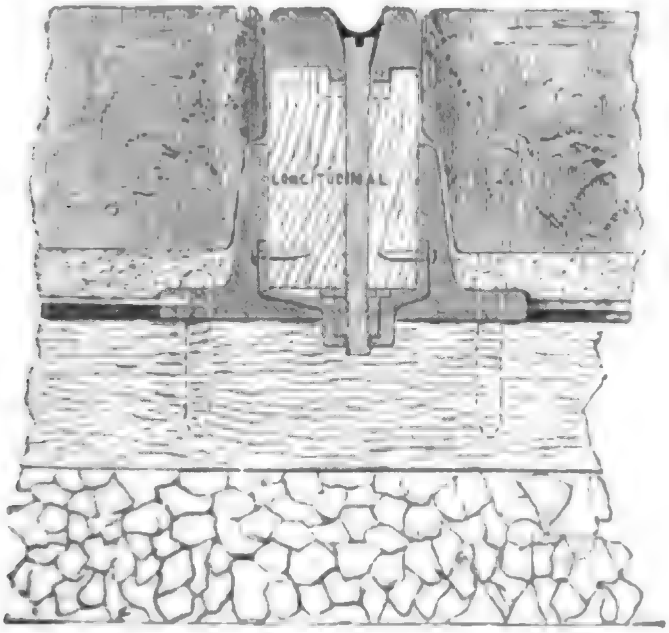


FIG. 55. Glasgow Corporation Tramways:—First system. Scale $\frac{1}{8}$.

	Miles.	Yards.
No. 1 Tramway:—Whiteinch, *viâ* Partick and Trongate, to Bridgetown	5	128
No. 2 Tramway:—Great Western Road, *viâ* Sauchiehall Street, Renfield Street, Jamaica Street, to Port Eglinton	3	967
No. 3 Tramway:—Junction of the 1st and 2nd tramways, *viâ* Derby Street	1	78
(9⅔ miles)	9	1,173

The gauge of the way, according to the Act of 1870, was required to be equal to the railway gauge, 4 feet 8½ inches. But a new element was introduced by the Act passed in 1871 for the Vale of Clyde Tramways, according to which their lines were to be constructed for the transit of railway rolling stock; and it was further provided that the Corporation should, if they thought fit, construct the Glasgow tramways to the same gauge as that of the Vale of Clyde lines, to secure a uniformity of gauge throughout the Glasgow district. It behoved the authorities, therefore, to look in advance, and while the contract for the first portion of the tramway was being drawn up, in 1871, it occurred to the engineers that, in order to give passage to railway waggons, the Vale of Clyde lines, and, therefore, also those of the Corporation, if the gauges were to be uniform, must be less than the normal standard gauge; for, what is strange at first sight, the gauge of 4 feet 8½ inches in the grooved rail does not answer for railway waggons. The reason becomes apparent when it is considered that the groove is not wide enough to clear the backs of the tyres. These are never less than 4 feet 5½ inches apart, a width which is 3 inches less than the normal gauge, equivalent to 1½ inches at each rail. But, as the width of the groove in the tramrail is commonly limited to 1⅛ inches, or at the most to 1¼ inches, the flanges of waggons obviously could not enter at all.

A correspondence was therefore instituted by Messrs. Johnstones & Rankine, in September, 1871, with a view to the establishment of a uniform gauge at the outset, as a standard for all the tramways in process of construction, or to be constructed, in or near Glasgow; such that, whilst the gauge would be continuous throughout the whole number of the group, it would be adapted for the transit of railway vehicles. Messrs. Johnstones & Rankine proposed to contract the gauge from the ordinary width by ¾ of an inch to 4 feet 7¾ inches, maintaining the minimum width of groove already adopted by them, 1¼ inches. By this compromise they would shift inwards the inner sides of the grooves of the two rails for each line to the distance apart of 4 feet 7¾ inches, minus twice 1¼ inches, or to 4 feet 5¼ inches. In this way the line would be adapted to receive railway waggons with a total lateral clearance of ¼ inch between the backs of the tyres and the inner edges of the grooves. It was apparent, nevertheless, that the 1¼-inch groove would be just wide enough to receive the flanges of railway waggons, which were of the same width, or thickness—1¼ inches. But the wedging which would have, in consequence, to take place if the wheels were to run on their treads or rolling surfaces, was obviated by the shallowness of the groove of the Glasgow rail, the depth being only ¾ inch; for it followed that the wheels would run on their flanges, which, being more than ¾ inch deep, would touch the bottom of the groove, and so prevent the wheel settling down and wedging itself into the rail.

Mr. Hopkins, as engineer for the Vale of Clyde Tramway, assented to the proposition for securing uniformity of gauge, and, in the first instance, recommended a gauge of 4 feet 7⅞ inches. For the purpose of settling the choice of these two widths Messrs. Johnstones & Rankine made arrangements for, and conducted experimental trials with, a short line of tramway laid to a gauge of 4 feet 7¾ inches, with the rails of the Glasgow tramways, and at the charge of the Corporation, within the station of the Glasgow and South Western Railway. Mr. Hopkins and others assisted at the trials, which took place on October 24, 1871. Railway waggons were run over the piece of tramway in a manner which was quite satisfactory; and the results of the trials led to the adoption, by general consent, of the gauge of 4 feet 7¾ inches for all the tramways of the Glasgow district.

The total width of the tramway, for a double line, amounted to 16 feet 10½ inches, constituted as follows:—

	Ft.	Ins.
Width of gauge, 4 feet 7¾ inches, × 2	9	3½
Width of interspace between lines of way . . .	3	11½
Four widths of rolling surface of rails, 1⅞ inches, × 4	0	7½
Two outer margins of pavement, 18 inches, × 2 . .	3	0
Total width	16	10½

For a single line the total width is 7 feet 11½ inches.

The excavation for the tramways was made to a uniform depth of 16¼ inches below the surface of the street. For the whole width a bed of bituminous concrete, 4 inches thick, was laid over the whole of the excavated bottom. The concrete consisted of slag fresh from the furnaces, thoroughly dry, broken to a 2-inch ring gauge, and British bitumen made from pure coal-tar pitch. The bitumen was to be used at the boiling point and mixed in the proportion of 31 lbs. per cubic foot of slag. The transverse sleepers were laid on a concrete bed, and after the longitudinal sleepers and rails had been correctly laid and adjusted the spaces between the cross-sleepers were made up with concrete of the same composition, flush with the upper surface of the sleepers. A half-inch stratum of bitumen was floated over this new level. Concrete was also packed under the longitudinal beams in the intervals between the chairs.

The rails, Fig. 55, weighed 60 lbs. per yard; they were 4 inches wide, and 1⅝ inches thick, at the tread. The rolling surface was 1⅞ inches wide, the groove was 1¼ inches wide and ¾ inch deep. formed semicircularly at the bottom, and the inner flange was ⅞ inch thick, and corrugated at the upper surface. The rolling surface was slightly rounded transversely; the fillet on the underside was ⅜ inch deep, and so increased the total depth of the rail to 2 inches. The rails were rolled to 24 feet in length, except 5 per cent. of the total quantity, which was of shorter lengths, not less than 14 feet. The bolt-holes in the grooves were ⅝ inch in diameter, countersunk to a diameter of 1 inch. The rails were to be made from piles of selected puddle-bars of mine iron, to produce a hard granular rolling surface, and were to be of tough fibrous iron at the underside. They were bolted to the sleepers with ⅝-inch bolts, of which there were eight to each rail of 24 feet long.

A portion of the points and crossings were to be of cast iron, 2 inches thick, and others of wrought iron, 1½ inches thick, corrugated at the surface. The chairs were of cast iron.

Three-eighths inch fish-plates, 12 inches long, were placed under the ends of the rails.

The longitudinal sleepers were of American white oak, 4 inches wide and 6 inches deep, secured to the chairs by ¾-inch oak pins. The transverse sleepers were of Baltic timber, 4 inches deep, 7 inches wide at the joints of the longitudinal sleepers, and 6 inches wide intermediately. All the timber was creosoted with 8 pounds of creosote per cubic foot of timber.

The interspaces, together with a breadth of 18 inches on each side of the way, were to be paved with granite from Furness quarry or Bonawe quarry. The stones were to range from 4 inches to 7 inches deep, as might be required, and to be laid on a bed of sand of from 1 inch to 1½ inches deep, laid on the bituminous coating. The stones were to be jointed for ¾ inches on each side of each rail with British bitumen, the remainder with lime grout. The surface of the pavement was formed with a natural slope of 1/16 inch in one foot from the centre line.

The use of bitumen for the joints was abandoned, as on experiment it was found that the bitumen ran and spread beyond the specified width and under some of the stones, and the design could not profitably be carried out.

The contractor was to maintain the whole of the work for six months after completion, and to replace all rails failing within 12 months. He could re-use, after re-dressing, the paving stones interfered with, so far as they were suitable for the work.

The total cost of construction of the tramway under the first contract was as follows:—

GLASGOW CORPORATION TRAMWAYS.—COST.

1872–73.	Length, single line.	Total cost.	Cost per lineal yard.	Cost per mile, single line.	Charge for maintenance for six months.
	Yards.	£	£	£	£
No. 1. 1st piece	8,281	27,850	3·363	5,919	30
,, 2nd ,,	6,286	16,144	2·568	4,519	100
,, 3rd ,,	2,920	6,258	2·143	3,772	20
No. 1 . . .	17,487	50,252	2·873	5,058	150
,, 2 . . .	12,234	30,835	2·521	4,437	20
,, 3 . . .	3,195	7,442	2·329	4,100	10
Totals . .	32,916	88,529	2·689	4,733	180

The variations in the cost per yard and per mile for the different pieces arise chiefly from the item of paving. In the first piece of No. 1 Tramway, the roadway was of macadam, and the tramway was laid with entirely new paving; whilst in the third piece the roadway was paved throughout, and the old stones were re-dressed and used for the tramway. In the other pieces the roadway was partly of macadam and partly of paving. The items of cost for paving, included in the above totals, were respectively as follows:—

GLASGOW CORPORATION TRAMWAYS.—COST OF PAVING.

1872—73.	Cost of paving.	Cost per lineal yard, single line	Cost per mile, single line.
	£	£	£
No. 1. 1st piece . .	12,370	1·494	2,629
,, 2nd ,, . .	4,195	0·667	1,175
,, 3rd ,, . .	1,010	0·346	609
No. 1	17,575	1·005	1,769
,, 2	8,476	0·693	1,220
,, 3	1,697	0·531	935
Totals for paving .	27,748	0·843	1,484
Do. for tramways proper	60,781	1·846	3,249
Total whole cost . .	88,529	2·689	4,733

From these data it appears that the average cost of construction per mile of double way was:—

For the tramway proper	£6,498	per mile, or	69	per cent.
For paving . . .	2,968	,,	31	,,
Total . .	£9,466	,,	100	,,

Schedule of Prices for First Contract, 1872—73.

	£	s.	d.	
Excavating macadam and removing the same for double line	0	7	0	per lineal yard.
Ditto for single line	0	3	6	,,
Lifting causeway, and excavating stuff and removing the same for double line	0	5	0	,,
Ditto for single line	0	2	6	,,
Furnishing, laying and completing bituminous concrete under transverse sleepers for double line	0	14	2	,,
Ditto for single line	0	6	8	,,
Furnishing, laying and completing bituminous concrete upon the preceding layer to 1½ inch below paving stones, 6 inches deep, or to from 1 to 1½ inches below paving stones 7 inches deep for double line	0	14	2	,,
Ditto for single line	0	6	8	,,
Rails laid complete	9	9	0	per ton.
Chairs ,,	4	10	0	,,
Bolts and nuts ,,	16	10	0	,,
Fish-plates ,,	10	5	0	,,
Washers ,,	12	0	0	,,
Spikes ,,	9	12	0½	,,
Cast-iron points and crossings laid complete	7	10	0	,,
Wrought-iron ditto	18	0	0	,,
Transverse sleepers, creosoted and laid complete—				
Joint	0	3	0	each.
Intermediate	0	2	6	,,
Longitudinal sleepers, ditto	0	2	4½	per lineal yard.
Ditto laid, not creosoted	0	2	2¼	,,
Allowance for extra width of longitudinal beams at points and crossings	3	0	0	per set.
Oak pins, 5½ inches long, ⅝ inch diameter	1	0	0	per 1,000.
Filling all bolt, spike, and pin holes with Archangel tar, per lineal yard of single line	0	0	0·343	per lin. yd.

SCHEDULE OF PRICES (*continued*).

	£	s.	d.	
Furnishing and laying sand 1½ inches deep under stones:—				
Double line	0	0	9	per lineal yd.
Single line	0	0	4½	,,
Furnishing and laying paving stones, jointing and grouting the same:—				
4 inches deep, new stones—				
Double line	2	5	0	,,
Single line	1	2	6	,,
6 inches deep, new stones—				
Double line	2	19	0	,,
Single line	1	9	6	,,

The liberal development of solidity exemplified in the construction of the first contracts for the Glasgow Corporation Tramways were extended likewise to the subsequent contracts.

CHAPTER IX.

GLASGOW CORPORATION TRAMWAYS, 1874—75.— *SYSTEM OF MESSRS. JOHNSTONES & RANKINE.*

FOLLOWING up the line of construction adopted in the first contract for tramways, in 1872, the engineers of the Glasgow Corporation Tramways, Messrs. Johnstones & Rankine, introduced several modifications of their earlier designs in the tramways more recently constructed, in 1874—75. In the course of the construction of the tramways, the work was gradually changed from that described for the first contract, to that which is now to be described, illustrated by Figs. 57 and 58.

The changes consisted of, first, the substitution of the flanged rail, or box-rail, for the flat rail, to admit of side fastenings.

Second, the use of a thinner layer of sand under the paving stones.

Third, the abandonment of the lower stage of concrete; that is, the concrete under the sleepers.

Fourth, the employment of lime concrete, instead of bituminous concrete.

Fifth, the grouting of the whole of the paving with bitumen, instead of lime.

The ways were laid to a gauge of 4 feet 7¾ inches, with an interspace of 3 feet 11½ inches between the two lines, whilst the paving was extended for a width of 18 inches at each outer side. The total width for a double line was made up thus:—

	Ft.	In.
Two widths of gauge	9	3½
Interspace	3	11½
Two strips of pavement	3	0
Four half-widths of rail (1⅞ × 4 =)	0	7½
	16	10½

For a single line the total width is 7 feet 11½ inches.

The steepest gradients of the tramways in Glasgow lie in Renfield Street. Going northwards from St. Vincent Street to Cowcaddens, the gradients are as follows:—

	Yards.			Yards.
1 in 27	for 96		1 in 81	for 88
1 ,, 21	,, 113		1 ,, 20	,, 215
1 ,, 26	,, 52		—	—
1 ,, 43	,, 22	Total	1 ,, 21	,, 586

The gradients in Great Western Road, west of Kelvin Bridge, Hillhead, are as follows:—

	Yards.			Yards.
1 in 37	for 85		1 in 41	for 85
1 ,, 27	,, 110		—	—
1 ,, 30	,, 37	Total	1 ,, 33	,, 415
1 ,, 33	,, 98			

For a double line, the roadway was excavated to a width of 17 feet, and, for a single line, to a width of 8 feet; to a uniform depth of 12½ inches below the intended level of the rails. The excavated surface was cleared of all refuse, sludge, loose or soft material, before the concrete and the sleepers were laid.

The rails were of wrought iron, and weighed 60 lbs. per yard; they were rolled in lengths of 24 feet, with about 5 per cent. of the total quantity in shorter lengths. In the character of the section, they are nearly the same as are laid in the Vale of Clyde Tramways. They are 3¾ inches wide, and $1\frac{5}{16}$ inches thick; the rolling surface, which is slightly rounded, is 1⅞ inches wide, the groove is 1¼ inches wide, and the flange at the inside is ¾ inch wide. The groove is formed with a flat floor, and is only $\frac{11}{16}$ inch deep, leaving a $\frac{3}{4}$-inch thickness of metal below it. The lower side flanges are fully $\frac{3}{8}$ inch thick and 1$\frac{3}{8}$ inches deep, thus making a total depth of 2$\frac{13}{16}$ inches. Comparing this, the new rail, with the old rail, Fig. 55, page 167, whilst the weights of the rails are both 60 lbs. per yard, there is a better distribution of metal in the new rail; for whilst it is $\frac{3}{16}$ inch thinner, it is, with the flanges, $\frac{13}{16}$ inch deeper than the first rail. Again, by the comparative flatness and shallowness of the groove, the new rail, though thinner, retains a sufficient thickness under the groove, which is the weakest part in grooved rails.

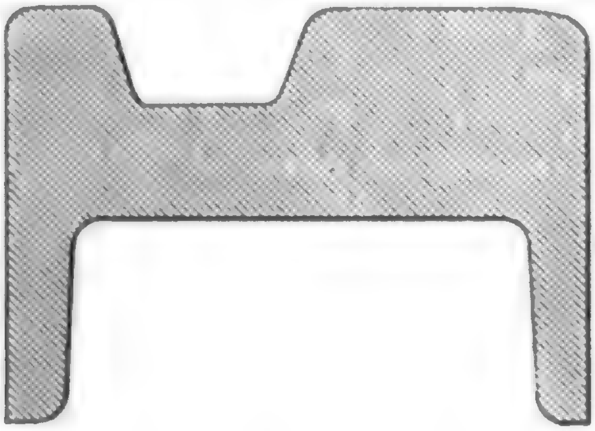


FIG. 56. Glasgow Corporation Tramways:—Section of Rail. Scale $\frac{1}{2}$.

The longitudinal sleepers, or beams, are of Baltic red timber, 4 inches wide and 6 inches deep, rebated at each side for the lower flanges of the rail, and not less than 24 feet in length. The joints of the beams are cut square. At curves the beams are sawn to the radius, and where the radius is less than 80 feet the beams might be reduced to 14 feet. The rails were drawn close to the longitudinal beams by means of a powerful cramp, and each rail of 24 feet in length was secured to the beam with side-fastenings, or staples, at each side alternately, and at a pitch of about 13$\frac{1}{2}$ inches on each side. Each joint of the rails is fished with an iron plate 8 inches long, 3 inches wide, and $\frac{3}{8}$ inch thick, let flush into the upper surface of the beam, and the end of each rail is fixed to the beam by two pairs of staples. Each 24 feet rail is fastened to the beams by a total of twenty staples. The staples are of Lowmoor iron and are in section ¾ inch by ⅜ inch; they have a total length of 8 inches, and are forged with two bends, of which the upper bend is chisel pointed, and passes through holes punched in the flange of the rails. The lower end is jagged.

The transverse sleepers are of Baltic red timber, 8 feet long and 4 inches deep. The sleepers at the joints are 7 inches wide and the intermediate sleepers are 6 inches wide. A joint sleeper is laid under each joint of the longitudinal beams; and at each joint of the rails, two intermediate sleepers are placed, at a distance apart, between centres, of not more than 2 feet. At other places the distance apart of intermediate sleepers is not more than 3 feet 8 inches between centres. Spike holes are bored through the sleepers.

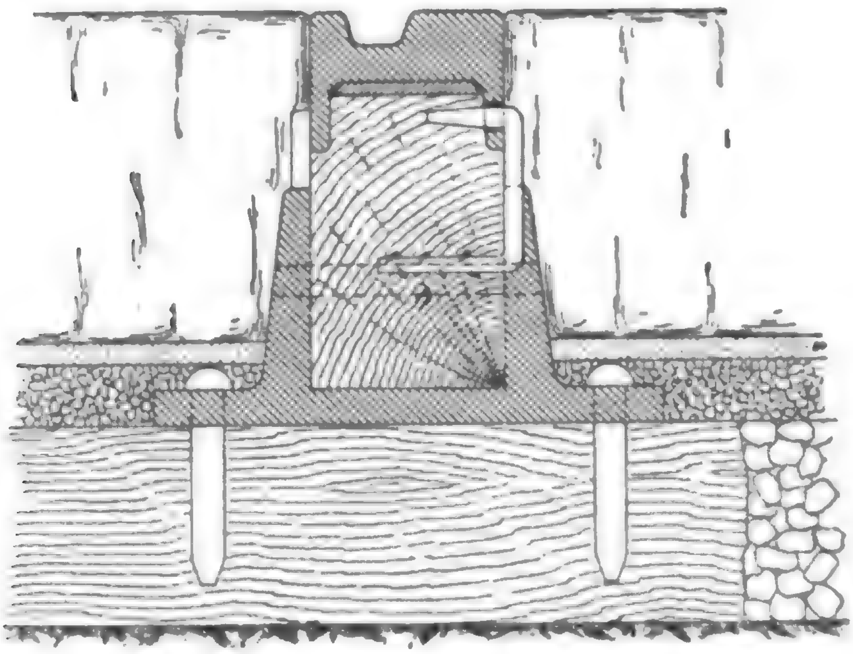


FIG. 57. **Glasgow Corporation Tramways:—Section of Rail and Sleepers, with fastenings. Scale ¼.**

All the timber was creosoted to the extent of 10 lbs. of creosote per cubic foot.

The longitudinal beams rest in solid cast-iron chairs, 4 inches wide between the flanges, 6 inches wide for the joints of the beams, and 4 inches wide intermediately. The sole of each chair is 9¾ inches long, and rests on the transverse sleeper, which is dressed to receive it. The sole is 1¾ inches thick, and the flanges taper from 1 inch thick at the base to ½ inch at the upper edge. The joint chairs weigh 21 lbs. each, and the intermediate chairs 14 lbs. each. The chairs are fastened to the sleepers by ⅝-inch wrought-iron spikes, 4 inches long, with cup heads, and tapered for ½ inch of length to ⅜ at the ends. The longitudinal beams are fixed in the chairs by ⅝-inch compressed oak pins, driven through the flanges of the chairs, and through holes bored in the beams; the ends of the pins are sawn off flush with the flanges.

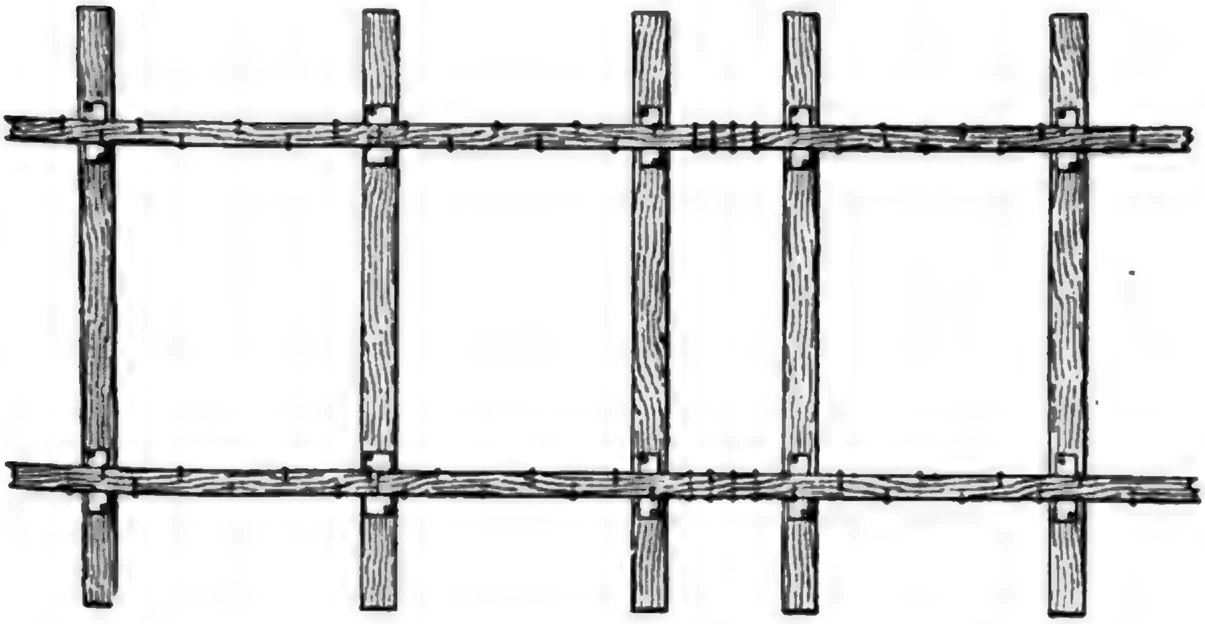


FIG. 58. Glasgow Corporation Tramways;—Plan of Sleepers. Scale $\frac{1}{24}$.

After the sleepers, beams, and rails were accurately laid and adjusted on the bottom of the excavation, the sleepers were packed underneath with fine concrete, composed as follows:—

	Measures
Whinstone shivers, broken to a ½-inch gauge	3
Sand	3
Orchard Roman cement	1
Arden lime	1
	8

The spaces between the sleepers were filled to the level of the upper surface of the sleepers by a concrete as follows :—

	Measures
Whinstone metal, to a 2-inch gauge, perfectly free from mud, clay, and dirt	6
Sand	1
Orchard Roman cement	1
Arden lime	1
	9

Upon this bed of concrete, and over the sleepers, a stratum of fine concrete was laid to such a thickness as to bring up the level to ½ inch below the paving sets. When the sets were 6½ inches deep, the thickness of the stratum was about 1¼ inches. Upon a ½-inch layer of clean sharp sand, the paving was bedded. The new paving was to be of granite from the Furness or Bonawe quarries, or, in the option of the Corporation, of Aberdeen granite. It was actually selected and wholly obtained from the Furness and Bonawe quarries. The stones were to be 3 to 4 inches wide, 6 to 7 inches deep, and 6 to 12 inches in length. They were set in straight and parallel courses across the lines of tramways, abutting closely on the rails, and the sets overlying the chairs were cut to suit them. The surface of the pavement was laid to a slope of ¼ inch per foot transversely, from the centre line of the way. It was grouted with a mixture of British bitumen, manufactured from pure coal-tar pitch, and pitch oil having a specific gravity of ·95. Oil was to be used in sufficient proportions to produce a plastic grout. The grout was run in hot, and the joints were completely filled with it.

The points and crossings are of cast iron, chilled at the upper side to a depth of at least ⅜ inch.

The improvements in economy and in efficiency, realised in the second system of way, compared to the first system, are very clearly brought out by a comparison of the illustrations. The 4-inch substratum of concrete was dispensed with, for it was found that the bottoms, as excavated, were sufficiently firm and solid to support the cross sleepers. In this way, economy in excavation also was effected, for the depth of material excavated was reduced by 4 inches, from 16¼ inches to 12¼ inches.

In both the earlier and the later designs, provision was made for rendering the work watertight, but differently. For, in the first construction, the water-proofing, consisting of the bituminous concrete, was laid at the foundation, and, in the second, it was laid at the surface of the road, consisting of the bituminous grout paving.

The adoption, in the later construction, of a thinner layer of sand for paving—⅛ inch instead of 1¼ inches—was clearly beneficial; it made a steadier pavement, which could be kept better up to the rails, and which demonstrated the advantages of the good foundation.

Finally, the most important improvement consisted in the substitution of the flange rail or box-rail, with side fastenings, for the flat grooved rail with a vertical bolt fastening.

GLASGOW CORPORATION TRAMWAYS.—SCHEDULE OF PRICES.

	£	s.	d.	
Lifting causeway, excavating and removing stuff from paved road—				
Double line	0	4	0	per lineal yard.
Single ,, ...	0	2	0	,,
Ditto, from macadamised roads—				
Double line	0	4	0	,,
Single ,, ...	0	2	0	,,
Furnishing and laying coarse and also fine concrete—				
Double line	0	11	6	,,
Single ,, ...	0	5	9	,,

Glasgow Corporation Tramways (*continued*).

	£	s.	d.	
Carting, bending, and laying rails complete—				
Double line	0	1	9	per lineal yard.
Single ,,	0	0	11	,,
Chairs, laid complete	7	17	0	per ton.
Joint plates, ditto	13	10	0	,,
Spikes, ditto	16	0	0	,,
Rail fastenings, ditto	44	0	0	,,
Chilled cast-iron switches, ditto	6	0	0	each.
Ditto crossings, ditto	5	5	0	,,
Transverse sleepers, creosoted and laid—				
Intermediate	0	3	2	,,
Joint	0	3	6	,,
Longitudinal beams, creosoted and laid	0	1	11	per lineal yard.
Oak pins	0	0	0½	each.
Furnishing and laying sand—				
Double line	0	0	9	per lineal yard.
Single ,,	0	0	4½	,,
Redressing and relaying paving stones—				
Double line	0	8	0	,,
Single ,,	0	4	0	,,
New paving laid complete—				
Double line	2	17	0	,,
Single ,,	1	8	6	,,
Pitch-grouting the pavement—				
Double line	0	12	0	,,
Single ,,	0	6	0	,,
Extra excavation	0	2	0	per cubic yard.
Ditto concrete	0	11	6	,,
Aberdeen granite for pavement—				
Double line	2	16	0	per lineal yard.
Single ,,	1	8	0	,,

QUANTITIES AND COST PER MILE, SINGLE LINE, OF THE GLASGOW CORPORATION TRAMWAYS (SECOND SYSTEM OF WAY), 1874—75.

Work and materials.	Per mile.				Per lineal yard.			
	Quantity.	Cost.			Quantity.	Cost		
WAY.		£	s.	d.		£	s.	d.
Excavation . .	1,694 cub. yds.	176	0	0	·96 cub. yds.	0	2	0
Concrete . .	630 ,, ,,	506	0	0	·36 ,, ,,	0	5	9
Sleepers . .	3,862 ,, ft.	247	10	0	2·20 ,, ft.	0	3	0¾
Chairs . . .	20·62 tons	161	17	2	26¼ lbs.	0	1	10
Spikes . . .	2,356 lbs.	16	16	7	1·34 ,,	0	0	2¼
Trenails—oak .	3,528 ,,	7	7	0	2	0	0	1
Rails . . .	94·3 tons	990	3	0	120 lbs.	0	11	2
Joint plates . .	1,099 lbs.	6	12	6	·62 ,,	0	0	0¾
Staples . .	11,440 ,,	224	14	0	6·5 ,,	0	2	6½
Totals . .	..	2,337	0	3	..	1	6	7
PAVEMENT.		£	s.	d.		£	s.	d.
Sand . . .	1,760 lin. yds.	33	0	0	1 lin. yd.	0	0	4½
New paving stones	4,594 sq. ,,	2,508	0	0	2·61 sq. yds.	1	8	6
Pitch grouting .	1,760 lin. ,,	528	0	0	1 lin. yd.	0	6	0
Total . .	..	3,069	0	0	..	1	14	11
SUMMARY.		£	s.	d.		£	s.	d.
Way . . .	..	2,337	0	3	..	1	6	7
Pavement . .	..	3,069	0	0	..	1	14	11
Total cost .	..	5,406	0	3	..	3	1	6

CHAPTER X.

GLASGOW CORPORATION TRAMWAYS.—MESSRS. JOHNSTONES & RANKINE'S MORE RECENT SYSTEM OF WAY, 1879.—*WEAR OF RAILS.*

It was apparent, nevertheless, with the prospect of the future employment of steam power for traction, and the attendant heavy rolling loads, that something better could be devised than the longitudinal timber beam and the box rail, a subject which had for a long period engaged the attention of the engineers. The Vale of Clyde Tramways, the construction of which is described in the next chapter, having longitudinal and side fastenings, have not withstood the steam haulage by engines. The ends of the rails were driven down into the timber, and the side fastenings worked loose.

Preparatory to deciding on the material—iron or steel—for the rails of the new system of way designed for haulage by mechanical power, the results of the comparative wear and tear of iron rails and steel rails under like circumstances, were investigated by the

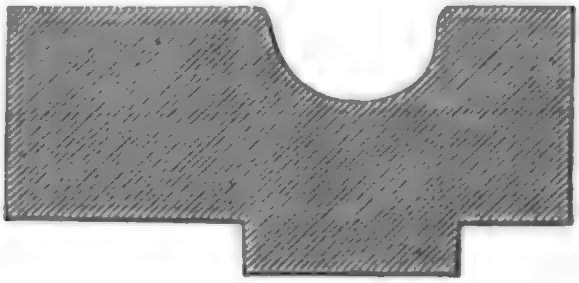


Fig. 59. Original Section of Rails, Glasgow.

engineers, Messrs. Johnstones & Rankine. Two rails, of the earliest section, one of iron and one of steel, laid in Paisley Road, within a few yards of each other; and two rails, one of iron and one of steel, laid in Argyll Street, were weighed when they were laid and when they were taken up. The original and the worn sections are illustrated by Figs. 59 and 63.

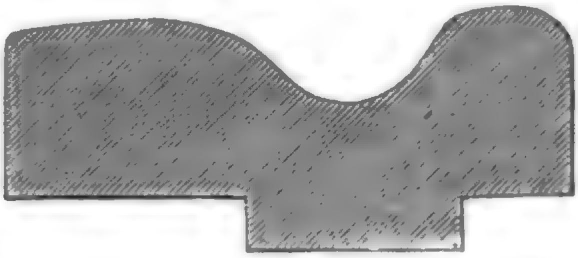


FIG. 60. Iron Rail, laid December, 1872. Worn Section.

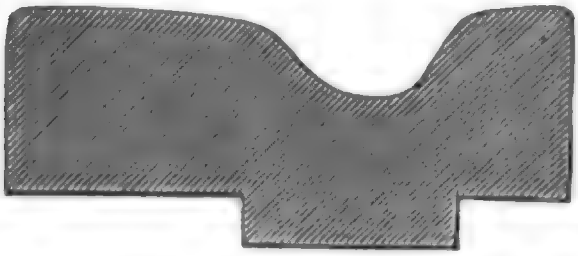


FIG. 61. Steel Rail, laid December, 1872. Worn Section.

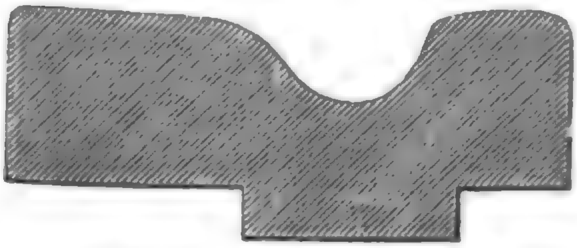


FIG. 62. Iron Rail, laid May, 1873. Worn Section.

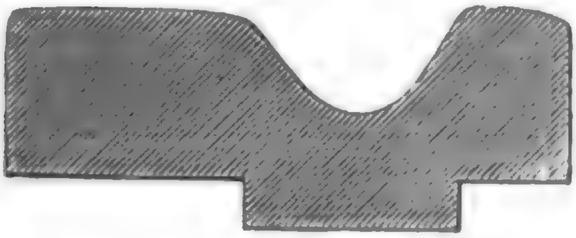


FIG. 63. Steel Rail, laid May, 1873. Worn Section.

FIGS. 59—63. Original and Worn Sections of Rails, Glasgow Corporation Tramways. Scale ½.

Paisley Road :—		
Iron rail, laid Dec., 1872.	Weight 480 lbs.	
lifted May, 1879.	Do. 436 lbs.	Loss 44 lbs.
Steel rail, laid Dec., 1872.	Weight 480 lbs.	
lifted May, 1879.	Do. 436½ lbs.	Loss 43½ lbs.
Argyll Street :—		
Iron rail, laid May, 1873.	Weight 480 lbs.	
lifted May, 1879.	Do. 441 lbs.	Loss 39 lbs.
Steel rail, laid May, 1873.	Weight 480 lbs.	
lifted May, 1879.	Do. 447 lbs.	Loss 33 lbs.

The loss of weight in the iron rails averages 41½ lbs.; and in the steel rails 38¼ lbs. But in the individual case of Paisley Road the wears were equal.

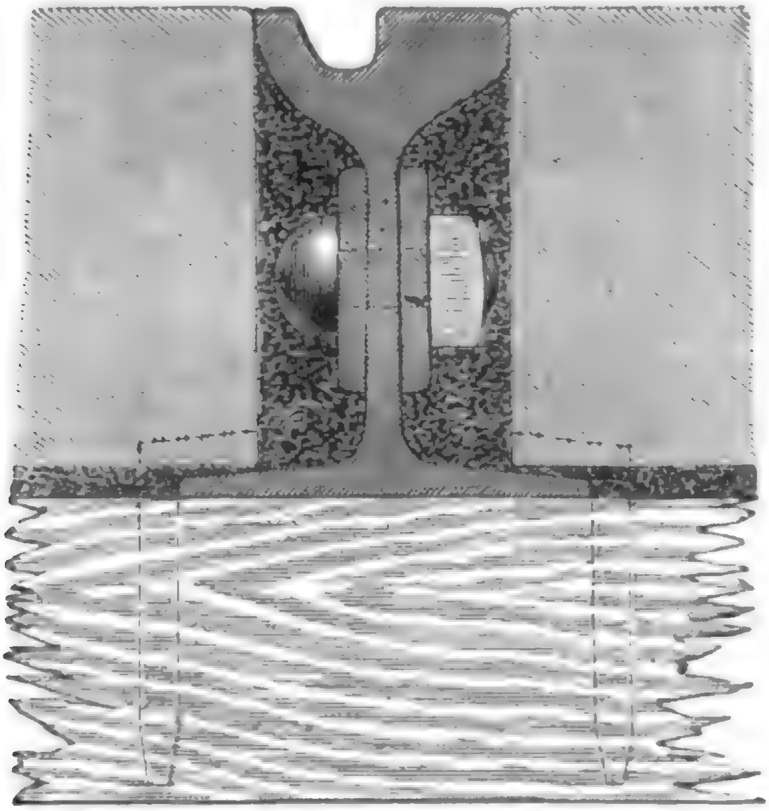
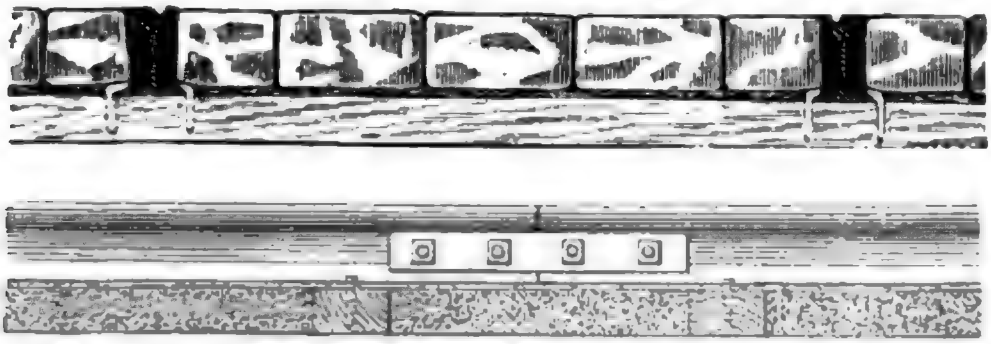


FIG. 64. Johnstones & Rankine's Way, Glasgow. —Rail and Sleeper. Scale ¼.

These results are remarkable, and in a sense disappointing, showing an unexpected degree of mediocrity in the steel rails; though the wear of the rails was more nearly uniform than that of the iron rails.

Steel was adopted for the material of the rails of the new lines; and the girder form for the section of the rails, as shown in Fig. 64. They were rolled by the Steel Company of Scotland, in lengths of 24 feet. The lip, or guard flange, is rolled out nearly square with the web, and is then turned upwards to form the groove. There was some difficulty and cause of trouble in perfecting the rolls. The greatest difficulty lay in maintaining the bottom flanges of the rails in their entirety for the whole width. The more nearly the mass of metal in the upper part of the rail balances that in the lower part the better for the work of rolling and the distribution of the metal. The friction in rolling tends to withdraw the thin sole plate from the extremities of the grooves in the rolls, and so to produce a sole of uneven width. That tendency is more powerful at and near the ends of the rails than in intermediate positions. In consequence, the rails require a good deal of trimming, and considerable allowance is made in the blooms for waste ends. Nevertheless, the rails can be rolled, if necessary, in clear lengths of 30 feet.



FIGS. 65, 66. Johnstones & Rankine's Way, Glasgow.

The construction of the new way is shown in Figs. 65 and 66. The rails are laid on and spiked to transverse timber sleepers, without the intervention of longitudinal timber sleepers. The ground is excavated for a depth of only 10½ inches below the surface of the road, for a minimum width of formation of 17 feet for a double line, and 8 feet for a single line. The transverse sleepers are of Baltic timber, 6 inches wide by 4 inches deep and 8 feet in length, creosoted to the extent of 10 lbs. of creosote per cubic foot of timber. They are laid on the floor of the excavation, on the system already shown in Fig. 58, page 179, one at each side of the joint of the rails, at 15 inches from the joint to the centre of the sleeper. The intermediate sleepers are laid at a pitch of 3 feet 10½ inches between centres; making seven sleepers to each 24 feet length of single line. They are bedded on and packed with fine concrete.

The rails are of Bessemer steel, of which the ultimate tensile resistance is 30 tons per square inch. The tread of the rail is 1¾ inches wide, the groove is 1⅛ inches wide at the surface, and the guard flange is ½ inch thick, making altogether 3⅜ inches of width. The rail is 6½ inches high, and the base is 5½ inches wide. The base is ¼ inch thick at the edge, and expands to 7/16 inch thick near the middle. The vertical web is ½ inch thick and tapers to ⅜ inch thick to the head. With these dimensions the rails weigh 79 lbs. per yard. They are rolled in lengths of 24 feet, with a proportion of about 5 per cent. in lengths of 20 feet. The rails are fish-jointed. In the web of each rail, at each end, 2 oval fish-bolt holes are punched, ⅞ inch deep and 1 inch long, respectively 3 inches and 9 inches from the end. The fishplates are 2 feet long, 3 inches wide, and ⅜ inch thick: they weigh 7 lbs. each. The bolts and nuts are of B. B. iron, ¾ inch diameter, with semi-spherical heads and square nuts. The design of the fishplates is opposed to that of current practice. The plates lie flat against the web of the rail, but do not take a bearing either above or below on the head or the base. The rails, it is contended, bedded direct on the concrete, are immovably held by the bituminous grouting; and the fishplates were applied rather with a view to keeping the ends of contiguous rails true to each other, until the work was completed.

The rails were laid to a gauge of 4 feet 7¾ inches: a gauge the origin of which has already been explained, page 168. The sole of each rail is brought close to the sleepers, to which each 24 feet rail is secured by 14 dogheaded spikes. Half-inch holes are bored entirely through the sleepers for the reception of the spikes. The spikes are of B. B. iron and are ½ inch square; they are

4 inches long under the head, and taper to ¼ inch thick at the point for a length of ¾ inch. The projection of the head is 1 inch from the stem of the spike.

After the sleepers have been packed, and the rails laid to proper line and level, the space excavated is filled between the sleepers, flush with them. The road metal from the material excavated, when used for making concrete, is carefully screened and cleaned. This, as well as new metal used, is broken to a 2-inch gauge. The concrete is composed of 5 measures of metal, 2 of sharp sand, and 1 of Portland cement, weighing not less than 115 lbs. per straked imperial bushel. The cement is required to be so finely ground that at least four-fifths of it can pass through a sieve of 2,500 meshes per square inch, or 50 meshes per lineal inch, and to be such that after being mixed neat in a mould and immersed in water for seven days, it resists, without breaking, a tensile force of 300 lbs. per square inch. The surface of the concrete filling is smoothed off with a layer of fine concrete composed of 4 parts of fine clean whinstone shivers, 1 part of sand, and 1 part of Portland cement. This fine concrete is laid upon the sleepers where the paving stones are of such depth that room for it is left under them. The finished surface is to be not more than ½ inch below the lower surface of the paving stones. The rails are thoroughly underpacked with concrete, so that they rest throughout on the concrete, not having any hollow or vacant spaces. All concrete is carefully mixed when dry, and afterwards watered and turned over at least twice on hard clean boards.

A layer of clean sharp sand, not less than ½ inch thick, is spread over the concrete, on which the paving is set. The joints of the paving are kept free of sand, and no more sand is used than is requisite for bedding the stones.

The paving extends for a width of 18 inches outside the outer rails, and is laid also between the rails. The paving for the double line of tramway, excluding the breadth occupied by the rails, is 15 feet 9 inches in width; and for a single line it is 7 feet 4½ inches in width. The new paving is of the granite of the Furness or Bonawe quarries, or of first-class close-grained Aberdeen granite.

When old paving is restored new stones are laid next the rails. The paving sets are all 6 inches in depth, from 6 inches to 12 inches long, and from 3 inches to 4 inches in breadth. The paving is laid in straight and parallel courses, to a uniform lateral slope of ¼ inch vertical to each foot horizontal, or at the rate of 1 in 48, flush with the rails. The stones are set close to each other, break bond for at least one-third of their length, butt truly and hard against the rail, and laid as much as is practicable so that the dog-spikes come between courses. But, when necessary, the stones are properly cut, so that they shall not rock on the spikes or other material.

After the paving is laid and thoroughly beaten, all the joints—next the rails as well as between the sets—are completely grouted with a mixture of best British bitumen, and pitch oil. The bitumen is manufactured from pure coal-tar pitch; the oil has a specific gravity of ·950. Each boilerful of grout is tested by suddenly cooling a portion of the grout in water; after being so cooled the grout should be plastic, and should not break by bending. The grout is boiling hot when used.

In constructing the tramway over Albert Bridge the sleepers were only 2 inches deep, when the full depth of excavation could not be allowed. The rails were bedded in fine concrete.

The contractor maintained the whole of the works, materials, and lines of tramways, for twelve months after the several dates of opening for traffic.

Schedule of Prices for Contract No. 7, September, 1879.

	Double line. s.	d.	Single line. s.	d.
Excavating and removing stuff from macadamised roads, per lineal yard	2	4	1	2
Concrete complete, per lineal yard	6	8	3	4
Carting, bending, and laying rails and fishplates complete, per lineal yard	1	8	0	10
Bolts and nuts for fishplates, per cwt.	10	6	10	6
Spikes per cwt.	10	0	10	0
Switches, laid complete, per pair	90	0	90	0

Schedule of Prices (*continued*).

	Double line. s.	Double line. d.	Single line. s.	Single line. d.
Complete rail crossings of cut rails, each	20	0	20	0
Creosoting and laying sleepers, each	0	10	0	10
Sand, per lineal yard	0	6	0	3
New 6-inch stone paving, per lineal yard	44	0	22	0
Lifting, redressing, and relaying old paving sets, per lineal yard	8	0	4	0
Pitch grouting, per lineal yard	8	6	4	3

Additional prices for extra work.

	s.	d.
Extra excavation, per cubic yard	2	6
Do. concrete, " "	10	3
New 4-inch cubes of Furness granite for double line, per lineal yard	35	6
New 4-inch cubes of Aberdeen granite for double line, per lineal yard	37	8
New 6-inch cubes of Aberdeen granite for double line, per lineal yard	48	0
Pitch grouting 4-inch cubes for double line, per lineal yard	8	0

On the rates contained in the foregoing schedule the extensions have been constructed. The quantities and costs per lineal yard and per mile of double line are given as follows. For the sake of comparison the corresponding details are here given for Contract No. 1, made in September, 1871.

Quantities and Costs of the Glasgow Corporation Tramways.

Contract No. 1, *September*, 1871. *In macadamised roads, with new paving.*

Double Line.	Per lineal yard. s.	Per lineal yard. d.	Per mile. £	Per mile. s.	Per mile. d.
Excavation	7	0	616	0	0
Concrete	29	6	2,596	0	0
Iron rails, 60 lbs. per yard, laid complete, £9 9s. per ton	20	1½	1,771	0	0
Chairs, laid complete, £4 10s. per ton	2	1½	187	0	0
Bolts and nuts, fixed complete, 330s. per ton	0	8	58	13	4
Fish-plates, fixed complete, 205s. "	0	4½	33	0	0
Washers, fixed complete, 240s. "	0	4	29	6	8

QUANTITIES AND COSTS (*continued*).

DOUBLE LINE.	Per lineal yard.		Per mile.		
	s.	d.	£	s.	d.
Spikes, fixed complete, 192s. 6d. per ton	0	3	22	0	0
Sleepers, creosoted and laid, 2s. 6d. to 3s. each	4	6	396	0	0
Longitudinal beams	9	6	836	0	0
Oak pins, 20s. per 1,000	0	1	7	6	8
Tarring bolt holes, &c.	0	1	7	6	8
Total for way	74	6½	6,559	13	4
Sand	0	9	66	0	0
New 6-inch paving stones, including grouting	59	0	5,192	0	0
Total for pavement	59	9	5,258	0	0
Total for way and pavement complete	134	3½	£11,817	13	4

Contract No. 7, *September,* 1879. *In macadamised roads with new paving.*

DOUBLE LINE.	Per lineal yard.		Per mile.		
	s.	d.	£	s.	d.
Excavation	2	4	205	6	8
Concrete	6	8	586	13	4
Carting, bending, and laying rails and fish-plates	1	8	146	13	4
Steel rails, 79 lbs. per yard, £8 10s. per ton Fish-plates, 14 lbs. per pair, £8 10s. ,,	26	1	2,295	6	8
Bolts and nuts, £10 10s. per ton	0	3	22	0	0
Spikes, £10 per ton	0	3	22	0	0
Sleepers, 1s. 11½d. each Creosoting and laying sleepers, 10d. each.	4	11	432	13	4
Total for way	42	2	£3,710	13	4
Sand	0	6	44	0	0
New 6-inch paving sets	44	0	3,872	0	0
Pitch grouting for do.	8	6	748	0	0
Total for pavement	53	0	£4,664	0	0
Total for way and pavement, complete	95	2	£8,374	13	4

The price of the sleepers, 1s. 11½d. each, delivered at the creosoting works, was, it may be noted, above their market value. It is an adjusted price, covering undelivered timber contracted for in 1873—74, when the market value of timber was high.

Irrespective of difference of rates, due to the state of the markets, it appears generally, in comparing the costs for the earliest and latest ways, that the comparative saving by the adoption of the new system is effected, for the most part, in the items of excavation and concrete, in which together the reduction amounts to £2,420. Add to this £409, the reduction of cost for the way proper, and the sum, £2,829, is the whole difference in cost in favour of the new way. The shallower and simpler structure of the new way has been rendered available by the employment of the stronger concrete, made with Portland cement.

Thus it is that Messrs. Johnstones & Rankine have logically matured an excellent system of tramway: having, by successive stages, reduced the quantity of excavation, concrete, and timber; simplified the design, increased the strength and durability of the work, and minimised the cost of construction.

In March, 1881, four miles of way had been laid in Glasgow, on the new girder system, the first portion of which had been opened one year previously. Now, in 1892, over nine miles have been constructed, the last portion having been completed in 1887. Practically, there has not been made any alteration of the system, excepting that the width of the fish-plates has been augmented so as to occupy the whole depth of the web of the rail.

The cost of the lines constructed between 1882 and 1887 varied from £7,000 to £8,000 per mile of double line. The prices of rails and fish-plates have varied considerably, those used in 1882 costing £9 5s. per ton, and those used in relation to the two succeeding contracts, extending from 1885 onwards, £5 17s. 6d. and £7 respectively for rails and fish-plates.

The prices for sleepers, including creosoting and laying, was reduced in 1882 to 2s. 1d. each, and thereafter to 1s. 6d.

The whole length of tramways in Glasgow and suburbs belonging to the Corporation is 31 miles of double line, the total cost of which, including that of the relative Acts, has been £345,000. The lessees find the necessary equipment for their working.

It was not till the beginning of 1886 that any of the tramways required renewal, their life on the busiest streets having thus been 14 years. Up to September last about 15 miles of double line had been renewed. In relaying the tramways the substructure is not interfered with. The rail, longitudinal beam, and chair, are lifted and removed entirely. The new or girder rail, of similar type to that used here since 1880, is designed to correspond in depth and come in place of these. It is thus laid on the old transverse sleeper and spiked to it as in the case of new tramways. The paving is taken up so as to restore it to the same level, and after redressing is relaid. The sleepers are, it is stated, all in good condition, having suffered little deterioration during the 14 years or so they have been laid.

As for the cost for renewal, it has naturally varied, being partly controlled by the importance of the street, the work having sometimes to be done during the night, involving the construction of cross-overs within short distances. The preparation of new paving stones is also an uncertain quantity, varying from 10 per cent. to 33 per cent., and in some cases even exceeding that. The average cost of renewal of a double line of tramway is from £4,000 to £4,500, less the value of old material, which amounts to about £350 per mile.

CHAPTER XI.

THE VALE OF CLYDE TRAMWAYS.

THE Act for the Vale of Clyde Tramways was passed in 1871. They consisted of two sections—from Park House Toll, Glasgow, to Paisley, Johnstone, and Govan; and from Port Glasgow to Greenock and Gourock. As before remarked, the Vale of Clyde line, between Glasgow and Govan, was, by the Act, to be constructed so as to admit of railway vehicles being passed over it: in fact, to carry loaded coal waggons from the Govan Railway Station to the ship-building yards on the route. It was laid to the gauge, 4 feet 7¾ inches, which was adopted by general consent for the tramways of the Glasgow District, as already noticed, and had been applied to the Glasgow Corporation Tramways.

The first piece of the upper section of the Vale of Clyde Tramways—from Park House Toll, Glasgow, to Govan—was constructed by the Corporation of Glasgow, under Mr. Hopkins as the engineer. The construction was commenced in July, 1872, and the line was opened for traffic on the 16th December, 1872. A portion of the lower section—between Greenock and Gourock—1½ miles in length, was opened in July, 1873. The remainder of the lower section, 3 miles in length, was constructed by, and leased from, the Corporation of Greenock. The lengths of line now open are as follows—

Glasgow and Govan . . .	2¼	miles	double line.
Greenock and Gourock . .	4½	,,	,,
Total	6¾	,,	,,

The Govan rail, Fig. 67, is of steel, and weighs 60 pounds per yard. The distribution of the material in the rail is less effective for resisting vertical stress than in the Dublin rail; but the thicker section was specially adopted for the transport of railway waggons, besides providing a more massive tread; the section also provided greater thickness under the groove—the weakest point.

The rail is nominally 4 inches wide. It is, in fact, 3⅞ inches wide at the surface, widening downwards to 4 inches at the edges of the flanges to facilitate the manufacture. The total depth is 2¾ inches. The tread, or rolling surface, is 1⅞ inches wide, slightly rounded, with a rise of $\frac{1}{16}$ inch. The groove is 1¼ inches wide, with sloping sides and a flat floor, and is only $\frac{11}{16}$ inch deep, adapted by its wideness and shallowness to receive the flanges of the wheels of railway waggons, which, being at least one inch in depth, of course take a bearing on the floor of the groove. "It was rather a violent thing to think of doing," says Mr. Hopkins, in his evidence before the Select Committee of 1877, "but the obligation was upon us, and it was the only way we could possibly hit upon, because, if we made the groove in the rail wide enough to receive the ordinary tyre of a railway carriage, it would be too wide for the ordinary traffic of a street." The ledge at the inner side of the rail is ¾ inch wide at the surface.

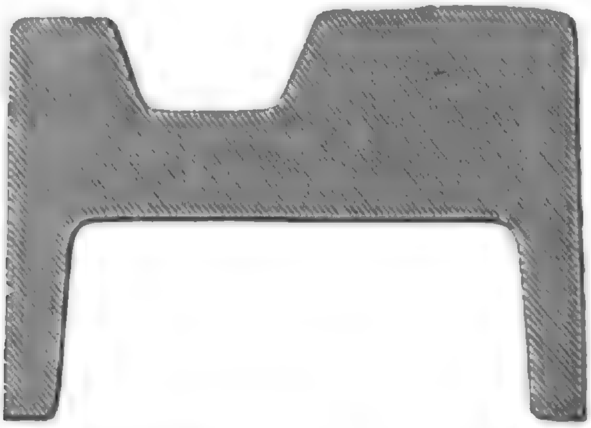


FIG. 67. Vale of Clyde Tramways:—Section of Rail. Scale ½.

The rails were rolled to a length of 24 feet, with 5 per cent. of the total quantity as shorter lengths.

The system of construction consisted of rails laid on longitudinal sleepers, bedded on a foundation of concrete laid the whole width of the way.

The lines of way, where the way is double, are placed at a distance of three feet apart between the rails. Including the usual outside breadths of 18 inches of pavement, the width of the tramway is made up as follows:—

	Ft.	Ins.
Two lines of way, 4 feet 7¾ inches gauge	9	3½
Interspace between lines	3	0
Two breadths of pavement, 18 inches	3	0
Four widths of rolling surfaces of rails, 1⅞ inches × 4 =	0	7½
Total width	15	11

In a single line the total width amounts to 8 feet 0¼ inch.

The roadway was excavated for the full width of the tramway—16 feet for a double line—to a uniform depth of 13 inches below the permanent surface. At junctions and crossings, where cross-sleepers were laid, the depth was increased to 17 inches, to make room for the sleepers. At places where the excavated bottom was not firm or solid, deeper excavations were made, and filled with hard materials or with concrete. A foundation of concrete laid with Portland cement was laid, 6 inches thick, in the bottom for the whole of the width. The concrete was of the following proportions:—

	Parts.
Portland cement	1
Ballast	7
	8

The cement was to be of the best quality, weighing at least 110 lbs. per striked bushel, and of such a fineness that 40 per cent. of it would pass through a hair sieve of 50 gauge. It was to support a tensile stress of 200 lbs. per square inch, one week after having been gauged neat, and kept immersed in water.

The ballast was to be clean and sharp, in the proportion of 6 parts of gravel, broken stone, or screened macadam, to 2 of clean sharp sand.

The ground was, in dry weather, to be well watered before the concrete was filled in.

The longitudinal sleepers were of best Memel timbers, 6 inches deep, 4 inches wide, sawn true and square, in lengths of not less than 20 feet, rebated to fit the rails. They were laid on the foundation of concrete. On curves having less than a radius of 200 feet, the sleepers could be of shorter lengths, and were sawn to suit the curves. Cross-sleepers of the same timber, 6 inches wide and 4 inches deep, at least 7 feet in length, were laid under the longitudinals to support them, at intervals not exceeding 4 feet between centres, at the points and crossings. A foundation of concrete, 6 inches thick, was laid for the support of the cross-sleepers. The timber was to be charged with creosote oil, having a specific gravity not exceeding 0·95, to the extent of 10 lbs. of oil per cubic foot of timber.

The rails were so laid that they extended to the right and left of the joints of the sleepers. For curves of less than 200 chains radius, the rails were to be bent to a true curve by the proper machine. Swaging, or bending by blows, was not permitted. Before the paving was laid, the rails were straightened and surfaced. The rails and sleepers were forced together by means of cramps, before the fastenings were driven. The cramps were used for each hole, and were screwed up as near the fastenings as possible.

The longitudinal sleepers were laid in pairs, and the ends were cut true and square. As in the Liverpool line, they were tied together except where cross-sleepers were used, at every joint and at intervals of from 4 to 5 feet, with wrought-iron tie-bars, 2 inches deep × ⅜ inch thick, having dovetailed ends, made of best merchant iron. These were let into dovetailed grooves, in cast-iron clip chairs, fitted tightly upon the longitudinal sleepers, and nailed to them with ⅜-inch nails, 2½ inches long. The cross-sleepers used at the joints and crossings are united to, and act as ties for, the longitudinal sleepers, by two pairs of cast-iron brackets, each longitudinal sleeper being lodged between the brackets, and fixed to them with ½-inch spikes, 3¾ inches long, chisel-pointed, and round headed, four spikes for each bracket. The joints of the rails are supported by joint-plates of best merchant wrought iron, ⅜ inch thick, 3 inches wide, and 8 inches long, rounded at the angles, and let flush into the longitudinal sleepers.

The fastenings for the rails were double-kneed staples, having 8 inches of total length, made of iron ¾ inch thick, and ⅝ inch wide. The upper part, to pass through holes in the flanges of the rail, was forged round and chisel-pointed; the lower part was jagged, and was driven into the sleepers. Each rail of 24 feet was fastened with 23 staples, applied to each side alternately; two pairs of them were applied to the end of each rail.

The staples and the other fastenings employed in the chairs, brackets, points, &c., were made of Lowmoor iron.

After the rails and the sleepers were secured to each other, they were raised to the proper level by means of folding wedges, and were truly surfaced and straightened. They were closely and completely packed with concrete underneath, over the whole surface. The concrete was finer and stronger than that which was employed for the formation, and was of the following composition:—

	Parts.
Portland cement	1
Clean coarse sand	4
	5

The points and crossings were of cast iron, of which the whole of the upper surfaces were chilled to a depth of at least ⅜ inch. Movable tongues were of cast steel.

The whole of the spaces between the rails, with the 18-inch breadths at the outer sides, were paved with the best whinstone causeway sets, from 3½ inches to 4 inches wide, and 6 inches deep, laid on a bed ot good clean sharp sand, 1 inch thick. All the sets were to be dressed true and square and free from cracks, chips, round or broken angles, or hollows on the sides. The paving was laid in straight parallel courses across the way, bordered at each side by a longitudinal course of sets 3 inches wide, upon which the macadam of the common roadway abutted. Where the stones came in contact with the chairs and the brackets, they were to be carefully cut with a chisel by a mason to fit the work—not to be broken with a hammer.

The sides of the roads next the tramways were made up with broken granite or whinstone. The paving was well rammed, and the joints were partly filled with coarse dry gravel, run with best British asphalte, and covered with sand. The upper surface of the paving finished flush with the surface of the rails.

[CHAPTERS XII. TO XIV. DEAL WITH VARIOUS WAYS HAVING WOOD SUBSTRUCTURE.]

CHAPTER XII.

BELOE'S SYSTEM.—SOUTHPORT TRAMWAYS.—WIRRAL TRAMWAYS.

THE Southport Tramways, opened in 1873, of which Mr. Charles H. Beloe was engineer, consist of a single line 4 miles in length, laid with flanged or box iron rails, fastened to longitudinal sleepers laid on transverse sleepers in concrete, to a gauge of 4 feet 8½ inches. The ground was excavated for a width of 8 feet, to a depth of 12½ inches below the surface of the roadway. A foundation of concrete, 3 inches thick, was laid over the whole of the bottom.

The concrete was composed as follows:—

	Measures.
Broken stone	3
Coarse sand, or fine gravel	1
Blue lias lime	1
	5

Upon this base, cross-sleepers of pitch pine, 6 inches wide and 3 inches deep, were laid at intervals of 6 feet between centres. Longitudinal sleepers of the same timber, 3 inches wide and 6 inches deep, were laid upon and let 1 inch into the cross-sleepers, to which they were secured with four staples at each intersection.

At the joints of the longitudinal sleepers, cast-iron brackets are employed to fasten them by spikes to the cross-sleepers.

SOUTHPORT TRAMWAYS:—QUANTITIES AND COSTS FOR ONE MILE, SINGLE WAY, 1873.

	£	s.	d.	£	s.	d.
Excavation, 8 feet wide:—						
Macadam, 3 inches deep, 4,693⅓ square yards @ 2½d.	48	17	8½			
Below foundation of roads, 9½ inches deep, 1,238 cubic yards @ 1s.	61	18	0			
Bottom of excavation levelled, 4,693 square yards @ ½d.	9	15	6½			
				120	11	3
Concrete, 8 inches deep (1,043 cubic yards), deduct for sleepers, 52 cubic yards, 991 cubic yards @ 1s.				445	19	0
Timber:—						
Longitudinal sleepers, pitch pine, 6 inches × 3 inches, 21 feet lengths, 10,560 lineal feet @ 5d.	220	0	0			
Cross-sleepers, notched, at 6 feet intervals, 7 feet long × 880 = 6,160 lineal feet @ 5d. .	128	6	8			
				348	6	8
Iron rails, 21 feet long, 1,760 × 2 = 3,520 yards, at 40 lbs. per yard, say 63 tons @ £13 . .				819	0	0
Staples:—						
Short, 4 at every joint, 2,008 @ 4 oz., 4½ cwt. @ 24s.	5	8	0			
Long, 4 at every joint . . 2,008						
Long, 4 at every yard of way . 7,040						
9,048 @ 4½ oz., 23 cwt. @ 24s.	27	12	0			
Twisted, 4 at every cross-sleeper, except at longitudinal joints,—880 cross-sleepers, less 251 joints, 629 × 4 = 2,516 @ 5 oz., 7 cwt. @ 24s.	8	8	0			
				41	8	0
Carried forward . .				£1,775	4	11

SOUTHPORT TRAMWAYS (*continued*).

	£	s.	d.
Brought forward	1,775	4	11
Brackets, double, 2 at each longitudinal joint; 502 joints × 2 = 1,004 @ 5 lbs. 6 ozs., 48¼ cwt. @ 14s.	33	15	8
Oak trenails, 6 to each longitudinal joint, 502 joints × 6 = 3,012 @ £6 per 1,000	18	0	0
Fish-plates, 502 @ 5·86 lbs., 26¼ cwt. @ 13s.	17	1	3
	1,844	1	10

EXCAVATION AND MATERIALS FOR TRAMWAY.

		£	s.	d.	£	s.	d.
Paving, 4,400 square yards:—							
Granite sets @ 6s. 2d. per sq. yd. Paving @ 4d. per sq. yd. Grout @ 6d. per sq. yd. Sand @ ½d. per sq. yd.	4,400 sq. yds. @ 7s. 0½d.				1,544	11	8
Making good between new and old pavement, 1,760 lineal yards @ 6d.					44	0	0
Labour, laying tramway, 1,760 lineal yards @ 1s. 10d.		161	6	8			
Labour, cutting beds for fish-plates, 502 beds @ 4d.		8	7	4			
					169	14	0

Carting:—

	Tons.	Cwt.
Rails and fish-plates	64	6¼
Brackets	2	8¼
Staples	1	15
Trenails	0	1
Timber	38	5
Granite sets	782	0

		£	s.	d.
Total weight, say 889 tons @ 1s. 6d.		66	13	6
Watching, lighting, and contingencies	say	100	0	0
Total cost		3,769	1	0
Credit:—				
Old materials	say	41	0	0
Net cost		3,728	1	0

Say £3,730 per mile.

The rails, weighing 40 lbs. per yard, are 3 inches wide, and 1¼ inches thick; and, with the side-flanges, are 2¼ inches deep. The width was limited to 3 inches, as it was thought that a rail of this width would offer less interference with ordinary traffic than a rail of the usual width, 4 inches; besides, it costs less in first outlay. The rails are secured to the longitudinals by staples, at intervals of 3 feet on each side of the rails. The joints are secured by two pairs of staples, at the end of each rail. A wrought-iron fish-plate, 15 inches by 2¼ inches, and ⅜ inch thick, is placed at the joints.

After the rails and sleepers were adjusted to the street levels, the space around the cross-sleepers, and for 2 inches above them, was filled with concrete, which was brought to a level 4½ inches below the surface level. The cross-sleepers thus became enveloped in a mass of concrete, 8 inches deep. Upon a ½-inch bed of sand, 4-inch cubical sets were laid, as pavement, and grouted.

The Wirral Tramway (Birkenhead, Tranmere, Rock Ferry, and New Ferry) is a single line, 3 miles in length, including sidings. It was constructed to the designs of Mr. Beloe, as engineer, and was opened in 1877. In the design of this line, 4 feet 8½ inches in gauge, the engineer materially simplified the construction compared with that of the Southport line. The rails are box rails, laid on longitudinal sleepers bedded in concrete, and connected by tie-bars. In the choice of this system of construction, in which tie-bars were substituted for cross-sleepers, the engineer was influenced by a desire to leave the already existing foundation undisturbed. The foundation consisted of a stratum of rock-pitching, or rough stones, laid in by hand, 10 inches in depth, and if cross-sleepers had been laid, the pitching would have been broken into to such an extent as to have seriously weakened the foundation. But, though the cost was considerably reduced by the use of tie-bars instead of cross-sleepers, the engineer has regretted that he did not take out the old pitching, and lay a foundation of concrete for the whole width of the tramway.*

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* *Proceedings of the Institution of Civil Engineers*, vol. l., page 41.

WIRRAL TRAMWAY:—QUANTITIES AND COSTS FOR ONE MILE, SINGLE WAY, 1877.

	£	s.	d.	£	s.	d.
Excavation, 8 feet wide:—						
Macadam, 3 inches deep, 4,693 square yards @ 6d.	118	0	0			
Below foundations of roads, 668 cubic yards @ 4s.	134	0	0			
Levelling bottom, 4,693 square yards @ 1d.	20	0	0			
				272	0	0
Concrete, 440 cubic yards @ 9s.				198	0	0
Timber, 2,000 cubic feet @ 2s. 6d.				250	0	0
Iron rails @ 52 lbs. per yard, 84 tons 6 cwt. @ £8 10s.				717	0	0
Staples, 15 cwt. @ £1 2s. 6d.				17	0	0
Chairs, 4 tons 16 cwt. @ £6				29	0	0
Fish-plates, 1 ton 11 cwt. @ £9				14	0	0
Tie-rods, 5 tons 2 cwt. @ £14				71	0	0
				1,568	0	0

EXCAVATION AND MATERIALS FOR TRAMWAYS.

	Tons.	Cwt.	£	s.	d.	£	s.	d.
Paving:—								
Granite sets, 759 tons @ £1 8s. 6d.			1,082	0	0			
Laying, grout and sand, 4,300 square yards @ 1s. 8¾d.			372	0	0			
						1,454	0	0
Making good between old and new pavement, 1,760 lineal yards @ 5d.						37	0	0
Labour, laying tramway, 1,760 lineal yards @ 2s. 6d.						220	0	0
Carting:—								
Rails and fish-plates	85	17						
Chairs	4	16						
Staples		15						
Tie-rods	5	2						
Timber	30	12						
Granite sets	759	0						
Total weight, say 886 tons @ 2s.						89	0	0
Total						£3,368	0	0

The rails are of steel, and are wider and heavier than the Southport rails; they are 4 inches wide, weight 52 lbs. per yard, and are rolled to lengths of 21 feet. They are 1⅜ inches thick, with side flanges $\frac{11}{16}$-inch deep, making the total depth $2\frac{1}{16}$ inches. In improving upon the Southport rail, Mr. Beloe observed that the latter was not possessed of sufficient stiffness. The rails are bedded on longitudinal sleepers, 4 inches wide and 6 inches deep, and are fastened to them by wrought-iron side staples, ten to each rail, 6 feet apart at each side, except near the joints of the rails, where they are closer to each other.

The ends of the sleepers are lodged in cast-iron chairs, 9 inches long, tied together transversely by two ¾-inch tie-rods, which take a bearing by collars on the inner sides of the chairs, and pass through the chairs and the sleepers, and are fastened by nuts outside. The sleepers are likewise tied by three intermediate tie-rods passed through and screwed up outside.

The ground was excavated to a uniform depth of 7½ inches below the permanent surface; two longitudinal trenches in addition, 12 inches wide and 3 inches deep, were excavated under the sleepers, where the total depth amounted to about 10½ inches. When the rails and sleepers were adjusted in their places, the whole of the bottom of the excavation, as well as the trenches under the sleepers, were filled with concrete to a height of 3 inches above the bottom, thus embedding the sleepers to a depth of 3 inches, and leaving 4½ inches for paving. The paving consists of 4-inch cubes bedded on a ½-inch layer of sand.

CHAPTER XIII.

MACKIESON'S SYSTEM.—DUNDEE STREET TRAMWAYS.

THE Commissioners of Police of Dundee contracted in April, 1877, for the construction of 2,346 yards, or 1⅓ miles, of tramway, double line, to the design of their engineer, Mr. W. Mackieson, which was completed in July, 1877. The line passes between Dalhousie Terrace and the General Post Office, along Perth Road, Nethergate, Reform Street, and into Euclid Crescent.

According to the system of construction, which is similar to Mr. Hopkins' plan of 1873, flanged rails are laid on longitudinal beams or sleepers, which rest on a bed of concrete, and they are set to gauge by transverse tie-rods, dovetailed into cast-iron chairs. The surface is paved. Two sections of rails and sleepers are employed, smaller and larger, of which the lighter section is laid in the contracts—comprising a length of 1,562 yards—between Dalhousie Terrace and South Tay Street, and the heavier scantling is laid thence to the Post Office—a length of 784 yards—the busiest part of the route.

The lines are laid to a gauge of 4 feet 8½ inches, with a clear interspace of 4 feet between the rails. The rolling surfaces of the rails are, for the larger scantling, 1⅞ inches wide; and the paving is laid outside the lines for a width of 18 inches at each side. The total width for the double line of way is 17 feet ½ inch, thus:—

	Ft.	Ins.
Two lines, 4 feet 8½ inches gauge	9	5
1 interspace	4	0
2 breadths, of 18 inches	3	0
4 rolling surfaces (1⅞ inch × 4)	0	7½
	17	0½

The gradients of the lines are as follows, commencing at the Post Office :—

	Yards.		Yards.
1 in 100 for a length of	68	1 in 133 for a length of	65
1 ,, 451 ,,	167	1 ,, 47 ,,	98
1 ,, 100 ,,	200	1 ,, 77 ,,	67
1 ,, 210 ,,	234	1 ,, 133 ,,	88
1 ,, 50 ,,	67	1 ,, 34 ,,	166
1 ,, 36 ,,	48	1 ,, 50 ,,	131
1 ,, 31 ,,	228	1 ,, 121 ,,	263
1 ,, 47 ,,	99	1 ,, 250 ,,	126
1 ,, 117 ,,	132		
1 ,, 674 ,,	99		2,346

The gradients do not all fall the same way. There is a difference of level of 76 feet between the two extremities of the tramway—the Post Office being at the lower end.

The roadway was excavated, for the way of 60-pound rails, for a uniform depth of about 14 inches—exactly 13¾ inches—below the permanent level of the road, for the whole width of the tramway. The bottom was cleared of soft or otherwise unsuitable material, and levelled and beaten so as to secure a solid and uniform bottom. Upon the bottom was laid, for the whole width, a foundation of concrete, 6 inches thick, well pounded with a heavy beater. The composition of the concrete was as follows :—

	Measures.
Whinstone metal to a 2-inch gauge, screened with a ¼-inch sieve	2
Gravel, crushed whinstone, or broken bricks, to a 1-inch gauge	2
Clean, sharp river sand	2
Portland cement	1
	7

To support the longitudinal sleepers strips of cement mortar, composed of two parts of sand and one part of Portland cement, are laid on the concrete, 1 inch thick and 7 inches wide, increased to 9 inches wide at the chairs.

The longitudinal sleepers are of red wood, from Riga, Memel, or St. Petersburg, 4 inches wide, 5 inches deep, rebated for the 60-pound rail; and 3¼ inches by 5½ inches for the 34-pound rail.

They are at least 21 feet in length for the straight parts; and bent or sawn to curves, in lengths of from 12 feet to 18 feet. The whole of the timber is creosoted to the extent of 10 pounds of creosote per cubic foot. The ends of the sleepers are square-jointed, and rest on cast-iron chairs, 6 inches long, placed at intervals of from 4 feet to 5 feet. The chairs are nailed to the sleepers with $\frac{3}{8}$-inch chair nails, $2\frac{1}{2}$ inches long, having chisel points and cup heads. Transverse tie-rods of wrought iron, 2 inches by $\frac{3}{8}$ inch thick, are dovetailed into the chairs.

The rails are of wrought iron; the lighter and heavier rails weigh respectively 34 lbs. and 60 lbs. per yard. They are rolled in lengths of 21 feet, except 5 per cent. of the total number, which may be of shorter lengths, but not less than 12 feet long. The 60-lb. rails have a width of 4 inches and a thickness of $1\frac{3}{8}$ inches; they are $2\frac{3}{4}$ inches deep over the flanges, these being $1\frac{3}{8}$ inches deep, and averaging $\frac{5}{8}$ inch thick. The groove is $1\frac{5}{16}$ inches wide and $\frac{5}{8}$ inch deep, made with a flat floor, similarly to the Vale of Clyde and the Glasgow rails. The rolling surface of the rail is $1\frac{7}{8}$ inches wide; the outer flange is $\frac{13}{16}$ inch wide, and corrugated at the upper surfaces. The 34-lb. rail is $3\frac{1}{2}$ inches wide, and 1 inch thick: the groove is $\frac{5}{8}$ inch deep, and the thickness of metal under the groove is $\frac{3}{8}$ inch. The total depth of the rail is $1\frac{15}{16}$ inches. The rails are fixed to the sleepers by side fastenings or staples of Lowmoor iron, as shown, of which there are 21 for each 21 feet rail.

The points and crossings are of chilled cast iron, 2 inches thick, corrugated in correspondence with the rail.

The new pavement consists of Pitrodie whinstone sets, from 3 inches to 4 inches thick, 7 inches deep, and from 6 inches to 11 inches in length, with a granite margin averaging 6 inches wide, on each side of the rails, for the entire length of the tramway. Old paving sets, when re-dressed, were not to exceed $4\frac{1}{2}$ inches in thickness, and were not to be less than $6\frac{1}{2}$ inches in depth. The pavement was set on a 2-inch bed of coarse Earn sand, and laid "hard to hard"; it stands, as finished, $\frac{1}{4}$ inch above the level of the rails, leaving a residual thickness of $\frac{3}{4}$ inch of sand. The finished surface slopes on each side of the centre line of the tramway at the rate of at least $\frac{1}{8}$ inch per foot horizontally. The pavement is grouted with a composition of 1 part of ground Charleston lime, slaked, and 2 parts of sharp sand; and the surface is blinded with a layer of coarse river sand.

The works were maintained by the contractor for twelve months after being opened for traffic; except the rails, which were maintained good for two years.

Payments were made monthly on the work done, 10 per cent. being reserved as security, $\frac{6}{10}$ths of which was paid at the end of twelve months, and $\frac{4}{10}$ths two years after completion.

The works were constructed according to the annexed schedule of prices:—

DUNDEE STREET TRAMWAYS. SCHEDULE OF PRICES, 1887.

	£	s.	d.	
Lifting and laying aside road metal, including sets in crossings	0	0	6	per square yard.
Lifting, laying aside, and redressing old sets	0	1	0	,,
Excavation deposited in the pool at Magdalen Green, including dressing surface for concrete	0	2	6	per cubic yard.
Portland cement concrete, 6 inches thick	1	2	6	,,
Ditto mortar, 1 inch thick	0	1	0	per square yard.
Longitudinal sleepers of red wood (Baltic) 4 inches by 5 inches in 21-foot lengths, checked for rails, fish-plates, nuts and chairs, charged with creosote and bedded—one sleeper	0	1	6	per lineal yard.
Ditto in lengths of from 18 feet to 12 feet, 6 × 5 inches, cut to radius, and prepared as above	0	2	0	,,
Cast-iron chairs, weighing 11 lbs. each, bedded	0	7	0	per cwt.
Wrought-iron fish-plates, 2·3 lbs. each, punched for bolts	0	12	6	,,
Wrought-iron tie rods, 11·2 lbs. each	0	12	6	,,
Wrought-iron staples for side fastening	0	17	6	,,
Iron rails, 60 lbs. per yard, punched for side fastenings, secured to sleepers (£9 16s. per ton)	0	5	3	per lineal yard.

DUNDEE STREET TRAMWAYS (*continued*).

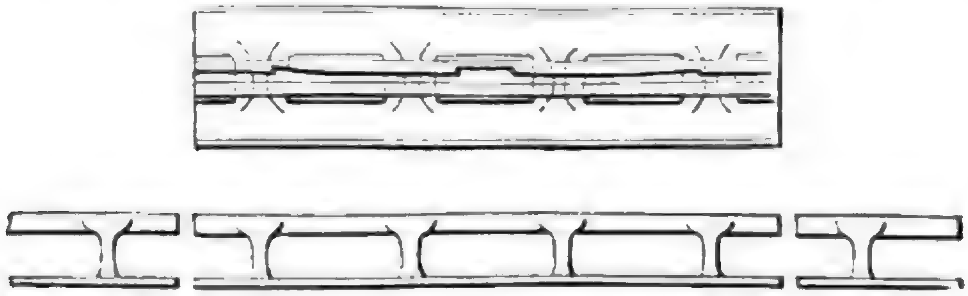
	£	s.	d.	
Iron rails, 34 lbs. per yard, prepared as above (£12 7s. per ton)	0	3	9	per lineal yard.
Iron rails at crossings and curves, bent to the required radii all together . . .	0	5	0	,,
Cast-iron points and crossings, secured to sleepers, including patterns	1	10	0	per cwt.
Paving with whinstone sets, from Pitrodie quarry, bedded on sand	0	9	0	per square yard.
Ditto with redressed sets, bedded on sand	0	1	0	,,
Grouting joints of pavement . . .	0	0	6	,,
Blinding pavement with sand	0	0	1	,,
Adjusting and reinstating macadamised roads and crossings, alongside the tramways, between paved margins and channels, with the old materials	0	0	2	per lineal yard.
Maintenance of work for twelve months for each of the three sections	20	0	0	,,

COST FOR 100 YARDS, SINGLE LINE, WITH 60 LB. RAIL, 1877.

Work and materials.	Quantities.	Rates.			Amounts.		
	Square yds.	£	s.	d.	£	s.	d.
Lifting and laying aside road metal	283	0	0	6	7	1	6
Excavation in road metal .	Cubic yds. 87	0	2	6	10	17	6
Concrete	47	1	2	6	52	17	6
Cement mortar	Square yds. 34	0	1	0	1	14	0
Longitudinal sleepers . .	Lineal yds. 200	0	1	6	15	0	0
Cast-iron chairs	Cwts. 13	0	7	0	4	11	0
Tie-rods	6·6	0	12	6	4	2	6
Staples	2	0	17	6	1	15	0
Chair nails	⅛	0	17	6	0	2	11
Rails, 60 lbs. per yard . .	Yards. 200	0	5	3	52	10	0
Fish plates	Cwts. 0·6	0	12	6	0	7	6
Whinstone sets	Square yds. 161	0	9	0	72	9	0
Granite sets (margins) . .	100	0	13	0	65	0	0

The cost of the way, exclusive of pavement, amounted to £151 for 100 yards, equivalent to £1 10s. 2½d. per lineal yard of single line, or to £2,658 per lineal mile. The cost for paving was £1 7s. 6d. per lineal yard, or £2,420 per mile. For way and paving together, the cost is £5,078 per mile, single line, or £10,156 per mile, double line. But, with certain compensations, together with the using up of such old paving stones as were serviceable, the total cost was expected not to exceed £13,300 for 1⅓ miles of double way, being at the rate of £9,975 per mile.

Besides the lines above noticed, new lines have been constructed and opened. The line between Dundee and Lochee, consisting of 1 mile 1,140 yards of double line, and 1 mile 5 yards of single line, making together about 2⅔ miles, was constructed on Gowans' system, and completed in December, 1879. The line from the Post Office to Stobswell, with a branch to Baxter Park, consisting of 1,304 yards of double line, and 1,614 yards of single line, together about 1⅔ miles, was completed in June, 1880. The Stobswell line was constructed with solid rolled girder rails, and the branch to Baxter Park, comprising 847 yards as single line, was constructed on Mr. William Mackieson's system.



FIGS. 68 and 69. Mackieson's Way, Dundee.—Sleeper. Scale $\frac{1}{24}$.

The rails, formed with a lower dovetail web, rest upon and are keyed down to long cast-iron sleepers, like open framing, comprising upper and lower horizontal members connected by upright standards at intervals.

The cast-iron sleepers, Figs. 68 and 69, are of great length—3 feet 11 inches. They are laid in line under each rail, 1 inch apart. They stand 6 inches high, and are made with shallow ribs on the underside to give lateral hold on the substratum. Each sleeper is made with four standards, placed at 12 inches apart, between centres, to support the rail bed, forming substantially an open girder, on which the rail is laid. The sole is 11¼ inches wide, and is generally ⅜ inch thick, made with openings in the space between the standards; the rail bed is 3 inches wide and 1⅞ inches deep, and the standards are 3 inches by 1 inch thick in section.

The rails, Fig. 71, weighing 36 lbs. per yard, are 3 inches wide, comprising the tread, 1½ inches wide, the groove 1 1/16 inches wide at the surface, and the guard flange, 7/16 inch wide. The rail is 1 3/16 inches deep above the sleeper, and its total depth, comprising the lower web or dovetail, is 2 3/16 inches. It is keyed to the sleeper by wrought-iron keys, which are 4 inches long by 1⅛ inches deep, and average ⅜ inch in thickness. These are tapered in thickness, and are driven into place horizontally, being introduced through long slots cut through the floor of the working groove of the rail. With this mode of fastening, the rails can be lifted when required, without causing any disturbance of the sleepers or the paving. The unoccupied portions of the slots are filled with elastic British bitumen. The rails were rolled in lengths of 20 feet, 24 feet, and 28 feet.

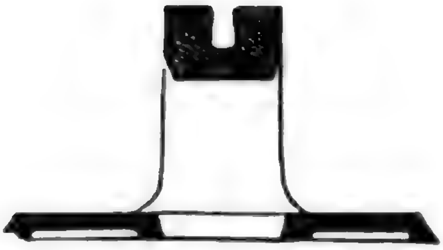


FIG. 70. Mackieson's Way, Dundee. —Section of Sleeper. Scale ⅛.

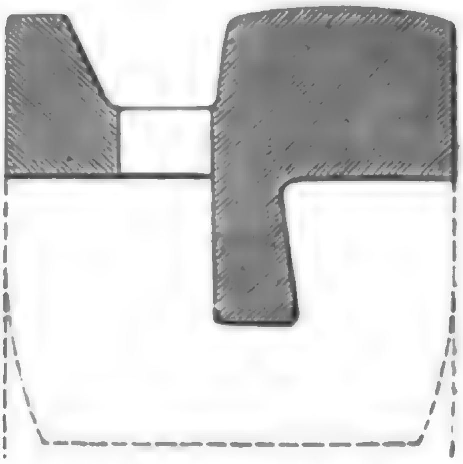


FIG. 71. Mackieson's Way, Dundee. —Section of Rail. Scale ½.

A foundation of concrete, in a layer 6 inches deep, is laid for the whole width of the way, and the outer paving pertaining to it.

The sleepers are bedded in this layer, so that the soles become flush with the upper surface. The concrete is composed of 4 parts of whinstone metal, to a 2-inch ring-gauge, 2 parts of sharp sand, and 1 part of Portland cement weighing 112 lbs. per bushel. The open spaces in the sleepers, under the rail bed, are packed with fine cement, composed of 1 part of Portland cement, 2 parts of sand, and 2 parts of metal broken to a 1-inch ring gauge. On this bed a layer of coarse Earn sand, from ½ inch to 1 inch thick, is laid, to receive the paving sets, which are of whinstone, 6 inches deep. The sets next the rails are laid hard against them, bedded on a layer of Portland cement and sand, in the proportion of 1 to 2. The paving is grouted with pitch-bitumen, manufactured from pitch, coal tar, and creosote oil, in the proportion of 80 gallons ot tar and 20 gallons of creosote to 1 ton of pitch.

QUANTITIES AND COSTS PER MILE, SINGLE LINE, OF MACKIESON'S SYSTEM—DUNDEE STREET TRAMWAYS, 1880.

		£	s.	d.	£	s.	d.
Steel rails, 36 lbs. per yard, 56½ tons	@	9	10	0	536	15	0
Wrought-iron keys, 19½ cwt.	,,	1	6	0	25	7	0
Cast-iron sleepers, 141½ tons	,,	7	0	0	990	10	0
Lifting and carting away macadam, 522 cubic yards	,,	0	1	4	34	16	0
Excavation, &c., 1,108 cubic yards	,,	0	1	7	87	14	4
Concrete, 6 inches thick, 782 cubic yards	,,	0	14	6	566	19	0
Laying tramway, 1,760 lineal yards	,,	0	2	2	190	13	4
Royalty, £75 per mile					75	0	0
Total for the way					£2,507	14	8

		£	s.	d.	£	s.	d.
Paving, &c., 2,836 square yards	@	0	6	10	968	19	4
Ditto on cement and sand next rails, 1,564 square yards	,,	0	7	0	547	8	0
Bitumen, &c., 4,400 square yards	,,	0	1	3	275	0	0
Total for paving					£1,791	7	4
Total for way and paving					£4,299	2	0

CHAPTER XIV.

MACRAE'S SYSTEM.—EDINBURGH STREET TRAMWAYS.

THE Edinburgh Street Tramways, of which Mr. John Macrae was the first engineer, were constructed in 1871—75, on the system of the flat groove rail, laid on longitudinal sleepers, on a bed of concrete. The several sections of the line were opened at various dates from 1871—75, as follows:—

Opened.	Section.	Double line.		Single line.		Total length of streets.	
		miles	yards	miles	yards	miles	yards
Oct., 1871	Haymarket and Leith	3	1,200	0	320	3	1,520
Apr., 1872	Powburn and Newington . . .	1	1,630	..	..	1	1,630
Nov., 1872	Morningside and Grange . . .	3	880	..	..	3	880
Dec., 1873	Newhaven Branch .	0	350	0	1,270	0	1,620
May, 1875	Portobello line . .	0	770	2	1,590	3	600
		9	1,310	3	1,420	13	970

The gauge of the way is 4 feet 8½ inches. The way is laid in the middle of the street. For double lines of way the lines are 9 feet apart between centres, and the total width is 17 feet, contributed thus:—

For a double line:—

	Ft.	Ins.
Distance apart of centre lines of ways . . .	9	0
Two half-widths of gauge	4	8½
Two rolling widths of rail (1¾ × 2 =) . . .	0	3½
Two breadths of 18 inches of paving . . .	3	0
	17	0

For a single line :—

	Ft.	In.
Width of gauge	4	8½
Two half-widths of rail	0	3½
Two breadths of 18 inches of paving . . .	3	0
	8	0

The gradients of the Edinburgh Street Tramways are unusually severe. The gradients on Leith Walk, which is the worst section, are as follows, commencing at the head of the incline, on the level of Prince's Street :—

	Gradient.	Length in yards.
	1 in 22	165
	1 ,, 14	43
	1 ,, 50	151
	1 ,, 24	137
	1 ,, 20	110
	1 ,, 24	71
	1 ,, 23	54
	1 ,, 29	166
	1 ,, 35	272
	1 ,, 42	100
	1 ,, 52	244
	1 ,, 43	218
	1 ,, 38	139
Average .	1 in 32	Total length . 1,870 yards, or 1 mile 110 yards.

The radius of the curve on the incline at the head of Leith Walk is 47 feet 8 inches, measured to the innermost rail.

The incline on the North Bridge is 1 in 17 for a length of 184 yards.

The average inclination on the Portobello Road is 1 in 30 for 1,500 yards. The steepest incline is 1 in 24 for 200 yards.

The following are particulars of construction and cost of works recently constructed on the Portobello Branch. The contract was let in July, 1874.

The contractor lifted the existing pavement or causeway, and at those portions of the street where the causeway bed was bad, or which was macadamised, the ground was excavated to a uniform depth, reckoned at about 13½ inches below the intended permanent surface, for a width of 17 feet for a double line, and 8 feet for a single line. The actual depth of excavation was less than 13½ inches, for the level of the renewed roadway was raised considerably.

A firm bottom was provided for the concrete. The normal thickness of the bed of concrete laid on the bottom of the excavation was 6 inches; a greater thickness was laid where it was necessary; but where the macadam of the existing macadamised roads was firm enough to form a foundation for the sleeper and the pavement, the surface was dressed and finished, when excavated, to a uniform level, to receive a thin coat of concrete. The concrete was carefully beaten, and the surface formed parallel to the surface of the street. The composition was as follows :—

	Measures.
Best Arden lime	2
Clean whinstone, broken to a size that will pass through a 2-inch ring	4
¼-inch Fisherrow or whinstone gravel . . .	1
	7

The sleepers are of red Baltic fir, from Riga, or of pitch pine, 4 inches wide and 5 inches deep, rebated at the upper corners to receive the fillets of the rails. The joints of the sleepers rest in cast-iron chairs, 6 inches long, the soles of which are let in the lower sides of the sleepers to present a flush surface to the concrete bed. The sleepers were creosoted with the best creosote, to the extent of 10 lbs. per cubic foot of timber, under a pressure of 200 lbs. per square inch.

The sleepers are tied to gauge, at intervals not exceeding 6 feet, by tie-bars of wrought iron, 2 inches by ⅜ inch thick, kneed reversely at the ends, and fixed to each sleeper by a ⅝-inch bolt, nut and washer. The rails are fixed to the sleepers by ⅝-inch bolts, nuts, and washer plates at the lower side. The bolts are countersunk, and are recessed in the head for a screw-key. All bolt holes in the wood were filled with Archangel tar at boiling-point, before the bolts were driven. The sleepers are bedded on a ½-inch layer of firm concrete, composed as follows:—

	Parts.
Portland cement	1
Fisherrow gravel	3
	4

mixed and tempered with mortar.

The rails are of wrought iron, rolled from large piles of the best puddled bars, so arranged that the lower portion of each rail is fibrous, and the rolling surface and upper portion of fine granular iron. The weight is 52 lbs. per yard. The rail is 4 inches wide, and 1½ inches thick, having two fillets on the under side, one at each corner, ⅜ inch square. At the upper side, the outer or rolling surface is 1⅜ inches wide, and the groove is 1¼ inches wide; the inner ledge is 1 inch wide, and is deeply corrugated, having 18 corrugations per lineal foot. The depth of the groove is ⅞ inch, leaving a thickness of ⅝ inch under the groove. The width of the groove at the bottom is 11/16 inch, and the splay of the sides of the groove is the greater towards the inner side of the rail. The standard length of the rail is 21 feet, or 7 yards, but a number not exceeding 5 per cent. of the whole quantity might be of less length, in whole numbers, of even feet, none of them less than 12 feet long. The variation of length allowed was ¼ inch. The rails are fixed to the sleepers by ⅝-inch bolts at 2 feet centres, except at each end, where the rail is fixed by two bolts at 4½-inch centres, of which the extreme bolt is 1½ inches from the end of the rail. The bolt-holes are made through the bottom of the groove, and the heads of the bolts when screwed home are flush with the bottom of the groove.

The ends of the rails are connected by wrought-iron fish-plates, 15 inches long, 3 inches wide, and ⅝ inch thick—one plate at each junction let flush into the sleeper—fixed by the four bolts already mentioned. The holes in the plates are formed oval, being ⅝ inch wide and ⅞ inch long, to allow for slight irregularities. The weight of a fish-plate is 7 lbs.

The points and crossings are of chilled cast iron or other materials.

A thin layer of clean sharp sand, or ¼ inch Fisherrow or whinstone gravel, may be spread over the concrete as a packing under the stones, to make up for inequalities of surface. But the stones rest direct upon the concrete where the packing was not required.

The causeway or pavement was laid over all the surface between the rails, and for a breadth of 18 inches upon each side, beyond the outermost rails. The sets are 3 inches wide, 7 inches deep, and of 10 inches average length, except such as are required to match the neighbouring pavement. They are of new granite or of new whinstone rock, from Westfield, Drumbowie, or Barnton quarries. They are laid dry, hard to hard, or in contact, and grouted with a mixture of equal parts of Portland cement and ¼-inch Fisherrow gravel, and finished with a thin coating of fine gravel. For the purposes of measurement the width of pavement for a single line of way is taken at 7 feet 4 inches; and for a double line 15 feet 8 inches, exclusive of the width of the rails.

The tramway was maintained by the contractor in good order for twelve months after the date of completion. The manufacturer of the rails was to take back and allow a deduction for any rails failing within two years from the date of manufacture. Payments, subject to deductions for penalties or damages, were to be made monthly to the extent of 90 per cent. of the value of the work done. The balance was to be paid at the end of six months after the date of completion.

The contract prices for work done in the construction of the Portobello section in 1874—75, were as follows, together with the schedule of prices for alterations, additions, deductions, or extra work :—

EDINBURGH STREET TRAMWAYS—COST FOR THE CONSTRUCTION OF THE PORTOBELLO SECTION, 1874—75.

From end of existing lines to East end of Waterloo Place.

	£	s.	d.
Lifting and laying aside present causeway, dressing surface of same; providing and laying bed of concrete; all materials for permanent way; new granite causeway blocks, grouted with cement, and coated with fine gravel, and finishing tramways complete, as specified—			
Double line, 27 lineal yards . . . . @ £6	162	0	0
Single line, 130 ,, ... ,, £3	390	0	0

From East end of Waterloo Place to Portobello.

Excavating macadam, and dressing surface of same; providing and laying bottom bed of concrete, all materials for permanent way; new whinstone causeway blocks, grouted with cement, and coated with fine gravel, and finishing tramways complete, as specified—			
Double line, 633 lineal yards . . . . @ £5 5s.	3,323	5	0
Single line, 5,070 ,, . . . @ £2 12s. 6d.	13,302	15	0
Providing and laying complete, points and crossings for 17 single line junctions, including extra for laying permanent way . . . . @ £20	340	0	0
Restoring gas and water pipes interfered with, or other works injured, and lighting, watching, and temporary fencing			
Preparing estimates, schedules of prices, &c., @ 1 per cent.	175	0	0
Total cost	17,699	0	0
Maintaining the whole of the works for twelve months after being opened for traffic . . .	250	0	0
Total cost, including one year's maintenance	£17,949	0	0

Edinburgh Street Tramways (*continued*).

The costs, not including points and crossings, may be abstracted as follows—

	£	s.	d.		£	
660 yards of double line	3,485	5	0	or	9,294	per mile.
5,200 ,, of single ,,	13,698	15	0	,,	4,637	,,
5,860 ,, (3·33 miles)	17,184	0	0	,,	5,160	,,
6,520 ,, (3·70 ,,) equivalent length of single line, cost					4,644	,,

Schedule of Prices.

	£	s.	d.	
Excavating macadam to the depth required for causeway and concrete, and dressing surface	0	2	0	per square yard.
Excavating the depth required for concrete, where present causeway is to be lifted	0	1	0	,,
Dressing and clearing surface of concrete where the existing concrete bed is allowed to remain	0	1	0	,,
Providing and laying new bottom bed of lime concrete, 6 inches thick, as specified	0	3	0	,,
Do., do., substituting cement for Arden lime	0	3	6	,,
Providing and laying fine bed of cement concrete, from 2 to 3 inches thick, as specified to be under sleepers	0	1	0	per lineal yard.
Do., do., substituting Arden lime for cement	0	0	9	,,
Cement grouting as specified	0	1	6	per square yard.
Grouting with Arden lime	0	1	3	,,
Lifting and laying aside present causeway blocks	0	1	0	,,
Lifting present causeway blocks, dressing and relaying them, including grouting with cement, and coating of fine gravel as specified	0	6	0	,,

SCHEDULE OF PRICES (*continued*).

	£	s.	d.	
Providing and laying new granite blocks, including grouting with cement, and coating of fine gravel as specified	0	13	0	per square yard.
Providing and laying new whinstone blocks, including grouting with cement and coating of fine gravel as specified	0	12	0	,,
Wrought-iron tramway rails as specified	10	0	0	per ton.
Cast-iron chairs for ends of sleepers	0	7	6	per cwt.
Bar-iron tie-rods, 2 × ⅜ inch	0	14	0	,,
Bolts and nuts for fixing rails to sleepers	0	0	3	per lb.
Ordinary bolts and nuts	0	0	3½	,,
Fish-plates	0	14	0	per cwt.
Longitudinal sleepers as specified	0	0	6	per lineal foot.
Providing, laying, and fixing complete, rails, sleepers, chairs, tie-rods, bolts, &c., as specified, single line	1	0	0	,, yard.
Do., do., but assuming rails to be provided by the Company	0	10	0	,,
Providing and laying chilled cast-iron point rails	5	0	0	each.
Do., do., with moveable point	6	0	0	,,
Do., do., crossings	5	0	0	,,
Extra price for laying in junctions from crossing to point, single line	0	3	6	per lineal yard
Do., do., cross-over roads, from point to point, single line	0	3	6	,,

QUANTITIES PER MILE, SINGLE LINE, 8 FEET WIDE, AND COSTS AS PER SCHEDULE RATES.

Work and Materials.	Quantities.	Rate.	Amount.		
	square yards.		£	s.	d.
Excavating macadam and dressing surface of same	4,693	2s.	469	6	0
Concrete bed, 6 inches thick	4,693	3s.	703	19	0
	tons cwts. lbs.				
Rails, 52 lbs. per yard .	80 0 0	£10 per ton	820	0	0
Bolts and nuts for rails .	5 3 0	3d. per lb.	144	4	0
Tie-rods	7 0 0	£14 per ton	98	0	0
Bolts and nuts for tie-rods	0 7 0	3½d. per lb.	11	8	8
Chairs	2 13 0	7s. 6d. per cwt.	19	17	6
Fish-plates . . .	1 12 0	14s. per cwt.	22	8	0
	lineal feet				
Sleepers	10,560	6d.	264	0	0
	lineal yards				
Cement for sleepers .	3,520	1s.	176	0	0
	square yards				
Whinstone causeway and grouting . . .	4,520	12s.	2,712	0	0
Total cost per mile	single line	..	5,441	3	2

The amount of cost per mile, thus estimated from the schedule rates, is greater than the actual amount per mile, already stated, according to the contract. The difference is accounted for, partly by the fact of a reduction having been made on the amount first made out; and partly by the raising of the level of the road when the tramway was laid, as a consequence of which the depth and quantity of the excavation, as well as those of the foundation of concrete, was generally less than the normal amounts as specified.

The renewal of the original ways was commenced in 1879, when Mr. Macrae substituted a solid steel girder rail on concrete for the older rail, shown in Fig. 72. The bed of concrete, laid for the whole width, 6 inches deep, was composed of 5 measures of broken whinstone, in pieces weighing from 2 ounces to 5 ounces, 3 measures of fine screened Fisherrow gravel, and 2 measures of best Portland cement. On this bed is laid a thinner stratum, 2 inches thick, of fine concrete, composed of 3 parts of whinstone or Fisherrow gravel, passed through a $\frac{3}{4}$-inch sieve, to 1 part of Portland cement. The rails were imbedded in this stratum while it was moist. They are of Bessemer steel, weighing 106 lbs. per yard, 8 inches in height. The flange base is 7 inches wide. The width of the tread is $1\frac{3}{8}$ inches, of the groove $1\frac{1}{16}$ inches, and the guard flange $\frac{7}{16}$ inch, making together about 3 inches. The rails are fixed at the joints, and the sides of each rail are filled up flush with fine concrete. The paving, of best granite, is 7 inches deep, and from 3 inches to $3\frac{1}{2}$ inches wide; the sets are laid on the bed of moist concrete, "hard to hard," and grouted with bitumen, or with Portland cement and $\frac{1}{4}$ inch Fisherrow gravel, mixed in the proportion of 1 to 2.

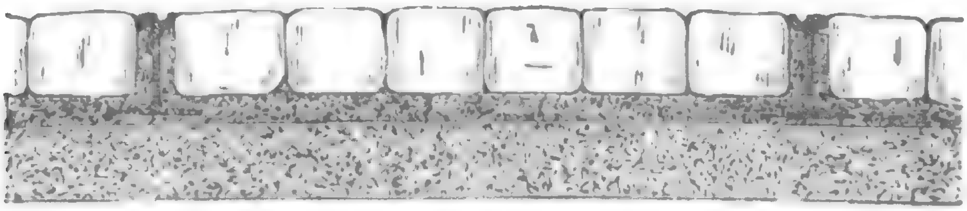
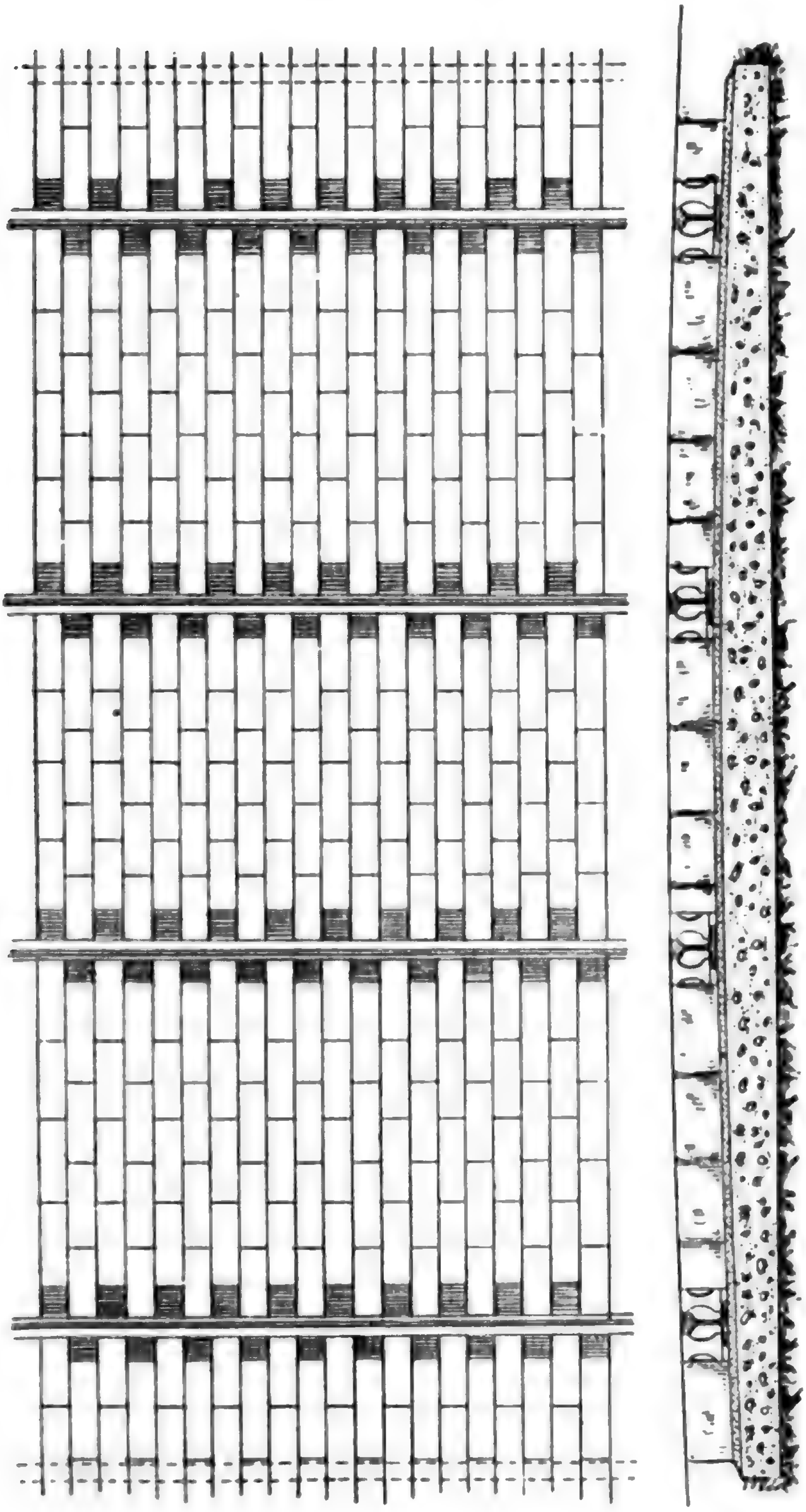


FIG. 72. Macrae's Way, Edinburgh. Scale $\frac{1}{24}$.

QUANTITIES AND COSTS PER MILE, SINGLE LINE, OF THE GIRDER RAILWAY, MACRAE'S SYSTEM—EDINBURGH STREET TRAMWAYS, 1879.

		£	s.	d.
Lifting old causeway and carting it away, 4,693 sup. yards	@ 6d.	117	6	6
Excavating foundation for concrete bed, depth 8 inches, 4,693 sup. yards . .	,, 5d.	97	15	5
Providing and laying concrete, 6 inches deep, 4,693 sup. yards	,, 2s. 10d.	664	16	10
Providing and laying bed of moist concrete, for bedding paving stones and tramway rails, 2 inches deep, 4,693 sup. yards	,, 1s. 2d.	273	15	2
Carried forward		£1,153	13	11



FIGS. 73 and 74. Edinburgh and Aberdeen Tramways:—Plan and Cross Section of Double Line of Way. Scale $\frac{1}{30}$.

QUANTITIES AND COSTS (*continued*).

		£	s.	d.
Brought forward		£1,153	13	11
Providing and laying new granite causeway, and grouting with bitumen 4,400 sup. yards	@ 10s. 5d.	2,291	13	4
Rails, 106 lbs. per yard, 166½ tons	,, £10	1,665	0	0
Fish-plates, 6 tons	,, £10	60	0	0
Bolts and nuts, ½ ton	,, £20	10	0	0
Laying rails, 1,760 yards	,, 1s.	88	0	0
Total		£5,268	7	3

Recently, a system of pavement, Figs. 73 and 74 (Livesey's patent), has been adopted, in which chilled cast-iron sets alternating with stone sets are laid alongside the rails, inside and outside. On this system, the wear of the surface is rendered more nearly uniform, and the tendency to wear into ruts is successfully counteracted. The same system has been adopted in the Aberdeen tramways, in which the way, complete, with chilled block paving, double line, cost £4 6s. per lineal yard. The suburban way, single line, without chilled blocks, cost £1 9s. 10d. per yard.

[CHAPTERS XV. TO XXIV. DEAL WITH VARIOUS WAYS HAVING METAL SUBSTRUCTURE.]

CHAPTER XV.

KINCAID'S IRON WAY.

Mr. Joseph Kincaid secured his first patent in March, 1872, for his system, in the forms illustrated by Figs. 75 to 77; of which Figs. 75 and 76 show rails of the ordinary construction at that period, supported at suitable distances apart upon supports formed with a flat base, and having an open space in the centre.

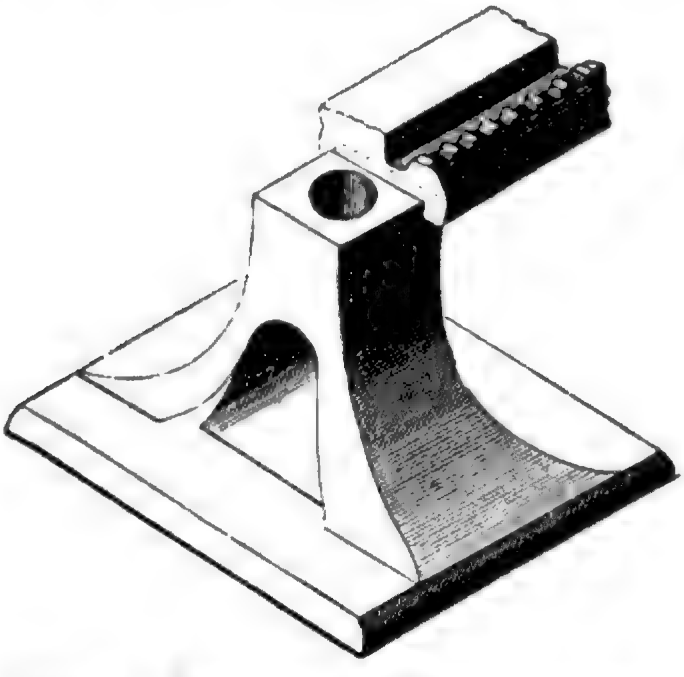


Fig. 75. Kincaid's Iron Way, as patented.

From the base, the support for the rail rises, having an open space or passage through it, in order that the concrete, in which the support is embedded, may enclose and surround it, so that it may be solidly embedded therein. The rail was fixed to the chair by a vertical spike through the groove, driven into a hard-wood plug, which was previously forced into a round hole in the top of the stool or support. As an alternative method of attachment, the rail might be fixed to the stool by side-fastenings consisting of spikes driven through holes in lateral flanges of the rail, made sufficiently deep, into plugs embedded horizontally in the head of the stool.

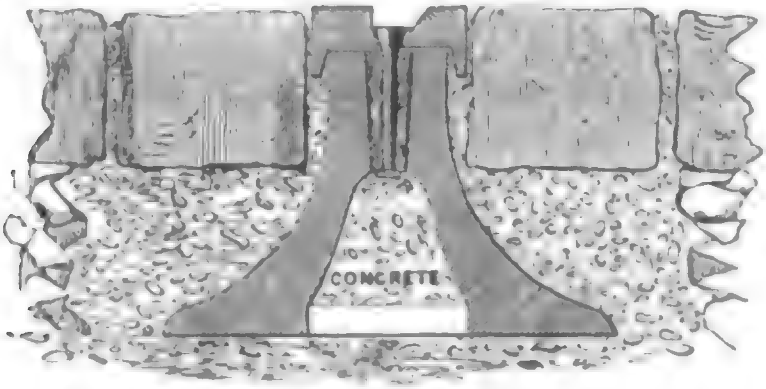


FIG. 76. Kincaid's Iron Way, as patented.

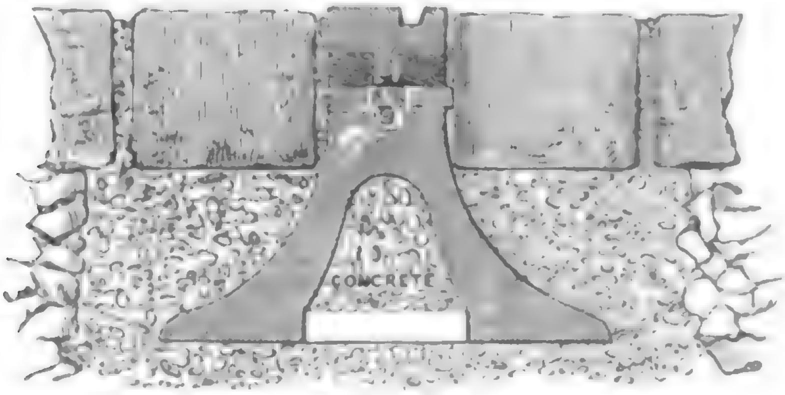


FIG. 77. Kincaid's Iron Way, as patented.

Mr. Kincaid showed also a method of fixing rails of **T** section, Fig. 77, consisting of an upper table, with a vertical flange or web, which was let into a slot in the head of the stool and fixed there by a horizontal taper cotter.

His first experiment was made on the Headingley branch of the Leeds Tramways, a quarter of a mile in length, which was laid with the rail, 47½ lbs. per yard, fixed to cast-iron stools at 3-feet centres.

In the design of the first portion of the Sheffield Tramways—the line to Attercliffe—which was opened in October, 1873, on his iron system, Mr. Kincaid employed a rail weighing 50 lbs. per yard. It had 2½ lbs. per yard more metal than the experimental rail at Leeds, and was of a much better section, having lateral flanges 1½ inches deep. Supported on cast-iron bearings 3 feet apart, the rail was found to be sufficiently strong and stiff. The paving, 5 inches deep, was laid on a bed of ashes 3 inches deep, and was grouted with an asphalted composition, pitch and tar. In excavating for the work, the ground was first removed to a uniform depth of 8 inches for the whole width of the way, and holes were dug to receive the foundations of concrete, and the stools for supporting the rails. The groove of the rail, it may be remarked, was, by superior order, made only 1 inch wide at the surface. It proved to be too narrow, and it bound the car-wheels on sharp curves.

The Dewsbury, Batley, and Birstal Tramway, for which Mr. Malcolm Paterson and Mr. Gomersell, successively, were engineers, constructed in 1872—75, was laid on Mr. Kincaid's system, according to his patent of 1872. The total length of the line —single line—is 3·325 miles, opened in sections successively as follows:—

	Miles.	
Dewsbury to Batley . .	1·325	July 25th, 1874.
Batley to Carlinghow . .	1	March 25th, 1875.
Carlinghow to Birstal . .	1	June 23rd, 1875.
	3·325	

There were ten sidings, eight of which were 66 yards long, and two were 55 yards long. The line is on an easy gradient of about one in two hundred, falling all the way, with slight exceptions, from Birstal to Dewsbury.

The rails are of wrought iron, and weigh 41 lbs. per yard. They are 3½ inches wide and 2 inches deep, and are carried on chairs 3 feet apart between centres, to which they are secured by vertical spikes to the bottom of the groove. The chairs were laid in concrete, run in with pitch, and the rails were packed underneath with a concrete composed of small broken stone and pitch.

The paving consisted of Dalbeattie granite sets, of which those laid between the rails were 4-inch cubes, and those laid in the 18-inch breadths outside were 6 inches deep. They were grouted with pitch. The paving was laid on a foundation consisting of a 2-inch layer of broken stone, covered with a 4-inch layer of ashes.

The cost of construction of the first 2¼ miles from Dewsbury, through Batley, to Carlinghow, in a paved road, amounted to £4,600 per mile; whilst the last mile, from Carlinghow to Birstal, in a macadam road, was constructed with paving complete for £4,000.

Mr. Kincaid, in his second patent, of January, 1876, introduced several improvements in the details of his iron system of tramway. He widened the body of the stool, or chair, to the same breadth as the rail, flush with it vertically, and thus widened the bearing for the rail by taking in the flanges, and presented an even surface as an abutment for the paving sets. He employed a rail like that of the Dewsbury line, hollowed out under the tread, and formed the head of the chair to fit into and take a bearing in the hollow. For the vertical plugs and spikes he substituted horizontal plugs in the chairs, with staples as side fastenings for binding the rail to the chair.

One of the later applications of Mr. Kincaid's system of way is illustrated by Figs. 78 and 79, exhibiting the construction of the Bristol tramways, laid in 1876. The Hull Street Tramways were constructed on the same system in the same year; the Leicester tramways in 1874; also, the more lately constructed sections of the Leeds tramways and the Sheffield tramways in the years 1876—77.

The gauge of these lines is 4 feet 8½ inches. The Bristol tramways are made in single line, 1 mile 1,452 yards in length, with maximum gradients of 1 in 17. The roadway, which was of macadam, was excavated for a width of 8 feet for a uniform depth of 8 inches; and holes for the foundation of the chairs, 3 feet apart between the centres, were excavated to a depth of 15 inches below the surface of the road, 18 inches wide and 16 inches long. The concrete employed was of the following composition:—

	Parts.
Clean sharp gravel or broken stone to a 1-inch ring-gauge	3
Sand	2
Fresh burned Aberthaw lime	1
	6

The holes were filled with concrete to a total depth of 8 inches, in which the soles of the chairs were embedded to a depth of 3 inches below the upper surface of the concrete. Concrete was also applied under each of the rails for its whole width, between the chairs, in some measure affording bearing surface, but designedly to occupy the space under the rail and keep it free from water.

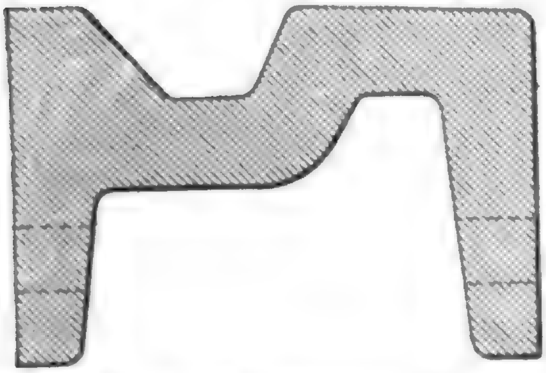
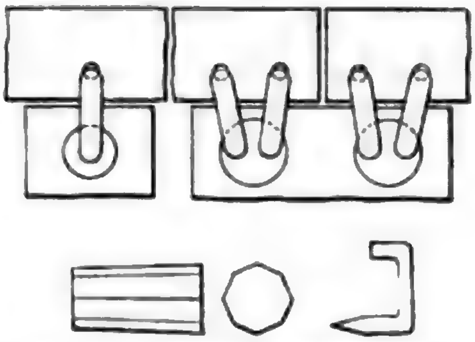


FIG. 78. Bristol Tramways: Section of Rail. Scale ½.



FIGS. 79. Bristol Tramways: Rail Fastenings. Scale ¼.

The rails were of wrought iron, rolled from a single ingot of best malleable No. 2 mine iron, weighing 43 lbs. per yard, with a margin of from 42 lbs. to 44 lbs., in lengths of 24 feet; except 5 per cent. of the whole number, which were to be of shorter lengths.

The rails were 3½ inches wide, and $\frac{9}{16}$ inch thick under the tread and under the groove; they are formed with two flanges, one at each side, 2$\frac{5}{16}$ inches deep, slightly taper in thickness, $\frac{7}{16}$ inch thick at the lower edges. The tread of the rail is 1⅝ inch wide, the groove is 1⅜ inches wide, and the outer border is ½ inch thick at the edge and corrugated. The groove is taper in section and the slope mostly towards the outside. The tread of the rail is flat, but is slightly inclined upwards, to the extent of $\frac{1}{16}$-inch rise, towards the centre of the rail. With such a formation, the contact of the car-wheels with the tread is concentrated at the inner edge of the tread; the load is, in consequence, fairly delivered on the rail at the middle of its width, and undue twisting action or deflection by side loading is obviated: a point of special importance for the stability of a suspended rail.

The chairs, of cast iron, have rectangular bases, 14 inches wide, 12 inches long, and ¾ inch thick, at a level 10 inches below the surface of the rails. They are, like the rails, 3½ inches wide at the head; and they give a bearing to the rails of 3½ inches at intermediate points, and 7 inches long at the joints. They are placed 3 feet apart between centres. The rails are fastened to the chairs by staples at each side, made of half-round bar-iron, best Staffordshire, which engage into holes punched in the rails, and are driven into hard-wood plugs, which are forced into holes at the heads of the chairs. There are two staples at each end of the rails, at each side, to make the joints; and, for a 24-foot rail, there are eleven staples at each side, or twenty-two in all. The plug holes in the chairs are slightly taper; at the larger ends they are 1¾ inches in diameter for the joint chairs, and 1⅜ inches intermediately.

The points and crossings are of cast iron, with wrought-iron tongues. The upper surfaces were file-dressed. There are three cast-iron chairs to each point, and two to each crossing.

All the castings are of No. 1 strong grey iron.

The paving consists of granite sets, 5 inches deep, laid, for the extreme width of 8 feet, on a bed of gravel 3 inches thick, spread on the bottom of the excavation. The paving was grouted with a liquid mortar, containing six parts of fine sand, to one part of fresh burnt lime; it was rammed before the grouting had set, and was again grouted.

ACTUAL COST OF THE BRISTOL TRAMWAYS (KINCAID'S WAY) PER MILE, SINGLE LINE, 1876.

		£	s.	d.	£	s.	d.
Rolled iron rails, 43 lbs. per yard, 68 tons	@	7	10	0	510	0	0
Cast-iron chairs, royalty included, 79 tons	,,	6	12	9	524	7	3
4,000 wood plugs, per 1,000	,,	4	10	0	18	0	0
9,700 wrought-iron staples, each	,,	0	0	2	80	16	8
Laying the way, including excavation and concrete, per lineal yard	,,	0	7	0	616	0	0
Total cost of way					1,749	3	11
Providing and laying granite pavement, including gravel bed and grouting, 4,400 square yards	,,	0	12	0	2,640	0	0
					£4,389	4	0

The work was maintained in good order for six months after it was completed and the line opened for traffic. Payments were made monthly, less 10 per cent., which was kept in reserve until the contract was completed.

LEICESTER TRAMWAYS.

In addition to the tramways, 4·44 miles in length, constructed in 1874, the Leicester Tramways Company (October, 1877) contracted for the construction of 5 miles additional length of tramway, on Mr. Kincaid's system. The rails were of Siemens steel, weighing 47 lbs. per yard. The staples were of Lowmoor iron. The following are particulars of the contract:—

COST OF NEW LINE OF THE LEICESTER TRAMWAYS (KINCAID'S WAY) PER MILE, SINGLE LINE.

		£	s.	d.	£
Rolled Siemens' steel rails, 47 lbs. per yard, 74 tons, delivered	@	8	7	6	620
75 tons Kincaid's cast-iron chairs	,,	3	18	6	294
Lowmoor iron fastenings or staples and plugs			..		100
Five pairs of cast steel points			..		50
Laying the way, including excavation for paving, as well as for the way and concrete, per lineal yard	,,	0	5	1	450
Total cost					1,514
Providing and laying Leicestershire granite paving, 8 feet wide, as follows: Sets, 6 inches by 4 inches outside the rails, and one course next the rails inside; "Randon granite," not less than 4 inches deep and 4 inches cube, over the remaining surface, per lineal yard, say	,,	0	6	4	1,300
Total cost for way and paving					2,814
Add, for engineering and legal charges					186
Total per mile, single line					3,000

SALFORD CORPORATION TRAMWAYS.

A more recent development of Mr. Kincaid's system, as exemplified in the Salford Tramways, lately constructed to the plans of Mr. Alfred M. Fowler, the borough engineer and surveyor, are illustrated by Figs. 80, 81, 82. The tramways consist of two lines, a double line, from Albert Bridge to Pack Horse Inn, 1 mile 1,437 yards long, and a single line, in Bury New Road, between the Kensal Toll Bar and Grove Inn, 1 mile 479 yards long. The roadways were partly paved and partly macadamised.

The rails are laid to a gauge of 4 feet 8½ inches. with an interspace of 4 feet between the two lines of the double way. The total width for a double way, including the 18-inch breadth at each side is 17 feet, constituted as follows:—

	Ft.	Ins.
4 feet 8½ inches × 2 = ...	9	5
Interspace	4	0
18 inches × 2 = ...	3	0
Four half breadths of rail (1¾ × 4) = .	0	7
	17	0

For a single line the total width is 8 feet.

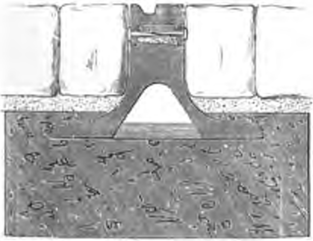


FIG. 80. Salford Corporation Tramways:—Kincaid's system, arranged by Mr. A. M. Fowler. Scale ⅛.

The pavement is lifted, or the macadam is excavated, for a uniform depth of 8 inches, for the whole width of 17 feet for a double line, or for 8 feet for a single line. Holes for the foundations of the chairs are excavated at 3 feet apart between centres, to a depth of 15 inches below the surface, or level of the rails; they are 18 inches long and 20 inches wide at the bottom.

The concrete is composed as follows, thoroughly mixed as required, on a wooden platform, and used fresh:—

	Measures.
Clean sharp gravel, broken stone, or macadam, to a 1-inch ring-gauge	4
Best Portland cement	1
	5

The holes excavated for the foundations of the chairs are filled with concrete in which the chairs are properly bedded and levelled; the concrete is rammed underneath and around each chair. Each block of concrete is 20 inches by 18 inches, by 8 inches deep, and the underside of the sole of the chair is sunk to a level of 1⅜ inches below the upper side of the block. The space under the rails between the chairs is filled with concrete, by enclosing the space at one side of the rail, and ramming in the concrete with wooden beaters from the other side.

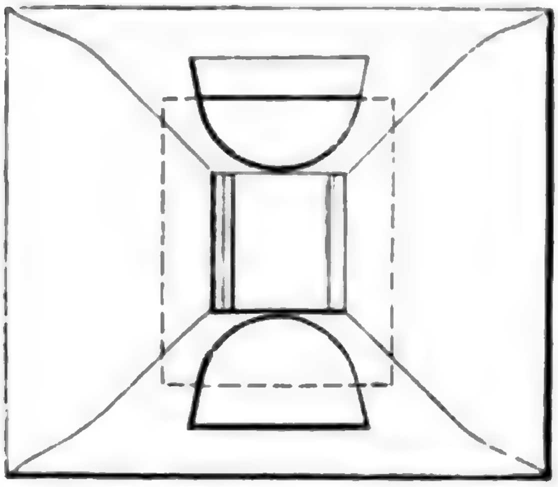


FIG. 81. Salford Corporation Tramways:—Plan of Chair. Scale ⅕.

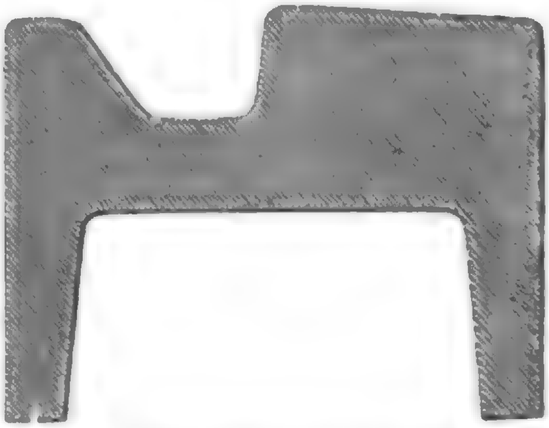


FIG. 82. Salford Corporation Tramways:—Section of Rail. Scale ½.

The chairs stand at a level 8⅜ inches below the surface of the rails, measured to the underside of the chair. The sole has an average thickness of 1 inch, the sides have a minimum thickness of ¾ inch; the neck of the intermediate chair is 3½ inches square, whilst the head, which takes the rail, is slightly taper, and 2½ inches wide. The head is flat on the top, and receives the rail with a flat bearing. The intermediate chairs weigh about 48 lbs. each, and the joint chairs 68 lbs. each. The plug-holes in the heads of the chairs are taper, 1 inch in diameter at the larger end, filled with ash plugs.

The rails, of iron, were rolled from piles composed of selected puddle bars, made from refined mine or pig iron, granular above, fibrous below, to weigh 50 lbs. per yard, and to be rolled to lengths of 24 feet. Five per cent. of the whole number of rails were rolled as shorter lengths, not less than 12 feet long. Rails weighing less than 50 lbs. or more than 52 lbs. were to be rejected. The rails are 3½ inches wide and have 2¾ inches of total depth, with a maximum thickness of 1⅝ inches. The tread or rolling surface is 1¾ inches wide; the groove is 1¼ inches wide and ¾ inch deep; and the outer edge is ½ inch wide at the surface, deeply corrugated at the rate of 14 corrugations per foot of length. The surface of the tread is flat and inclined, so that at the centre of the rail it is ⅛ inch higher than at the side. It is thus insured, as was remarked of Mr. Kincaid's Bristol rail, that car-wheels should take their bearing on the middle or centre line of the rail.

In each 24-foot rail 18 holes are drilled in pairs at 3 feet distances apart, through which the rails are fastened to the chairs by ⅜-inch round wrought-iron spikes, 2¼ inches long from the head, taper for part of their length. The spikes were of the very best quality and workmanship capable of being bent cold to form a right angle without fracture or flaw. The rails and chairs were pressed together by means of a screw clamp while the spikes were being driven; and the spikes were in such a position, near the upper part of the plug-holes, and were so driven that, by their action, the rail was brought well home to the top of the chair. Here the staple usually employed has been replaced by a direct acting spike, according to one of the forms described in Mr. Kincaid's patent of 1876. The heads of the spikes are ¼ inch thick, and they project by so much from the sides of the chairs, which otherwise, with the rails, present flat abutments for the paving sets.

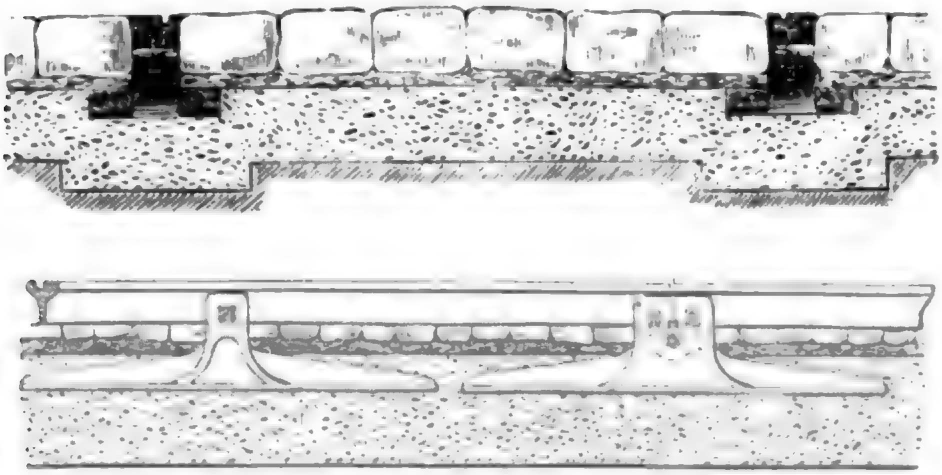
The points are 8 feet long, they are of cast iron, annealed cast steel, or of Vickers' forged steel. The crossings are made by cleanly cutting ordinary rails to the required angles so as to fit truly to the sides of the rails of the main road to be crossed. The adjoining flanges at the junction are bolted together with ½-inch bolts.

The paving consists of granite sets 6 inches deep, laid on a bed of sand 2 inches thick.

The whole of the work was maintained for twelve months after completion, except the rails, which were maintained for two years.

The cost of the work, excluding paving, was £1,925 per mile, single line.

Mr. Kincaid's later system of way, Figs. 83 and 84, laid in Bristol, was an advance upon his earlier practice—providing a wide foundation of concrete, and chairs and sleepers with a long base. This system, as here shown, was laid for lengths of a mile and a half, taken together, on the more lately constructed part of the Hotwells line, opened June 24, 1880; the Bedminster line, opened November 17, 1880; and the Horfield line, opened a day later, on the 18th. The other portions of these lines were laid on the same construction, except that the bases of the chairs were only 14 inches long and 12 inches wide.



FIGS. 83 and 84. Kincaid's Way, Bristol. Scale $\frac{1}{24}$.

The rail of the newer ways, Fig. 85, is of steel, weighing 50 lbs. per yard, formed with a central web and inclined flanks, to take a wedge-like bearing on the chairs. The groove is only 1 inch wide at the surface, the tread is 1⅞ inches wide, and the guard flange ⅝ inch wide, making together a width of 3½ inches. The total depth of the rail is 3⅝ inches, and the web is ¾ inch thick at the origin, tapering to ⅝ inch thick at the lower edge.

The chairs are of cast iron, of which the joint chairs weigh 76 lbs. each, and the intermediate chairs 64 lbs. each. They are 7½ inches in height, and have a flat base 10 inches wide by 2 feet 10 inches long. They are placed at distances apart of 3 feet from centre to centre, and are therefore only 2 inches clear of each other in line, making a bearing on the foundation practically continuous. They are gathered up in the body of the intermediate sleepers to a head 3½ inches long—the length of bearing for the rail—and 3½ inches wide, the same as the width of the rail, presenting two flat vertical flanks to the paving stones. The heads of the joint-chairs are six inches in length. The rails are fastened to the sleepers by means of iron cotters passed through the web of the rail, one cotter to each intermediate sleeper, and two cotters to each joint-chair, or one to each rail, with longitudinal clearance in the chair to allow for expansion. The joint-chairs are connected transversely by wrought-iron tie-bars, 1¾ × ⅜ inch thick, passed through the chairs, and screwed up with nuts at the outsides.

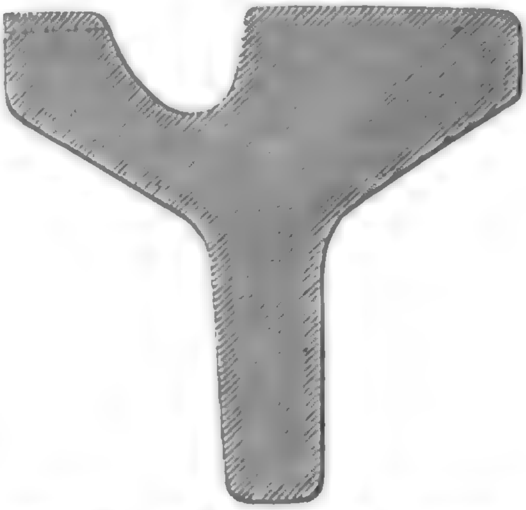


FIG. 85. Kincaid's Way, Bristol. —Rail. Scale ½.

A continuous foundation of lias-lime concrete, 6 inches deep, is provided, laid on the floor of the excavation, at a level 12 inches below the level of the rails, for the whole width of the way. Two longitudinal trenches in addition are excavated, one below each rail, 2½ inches deeper than the general excavation, at a level 14½ inches below the surface of the rails. At these trenches the concrete stands 8½ inches deep. Over the concrete a bed of gravel is laid, 1½ inches thick when spread, and beaten down to 1 inch when the sets are rammed. The paving sets, of granite, are 5 inches deep and 4 inches wide, and are grouted with lias lime and clean sharp sand.

QUANTITIES AND COSTS PER MILE, SINGLE LINE, OF THE KINCAID WAY, BRISTOL TRAMWAYS, 1880.

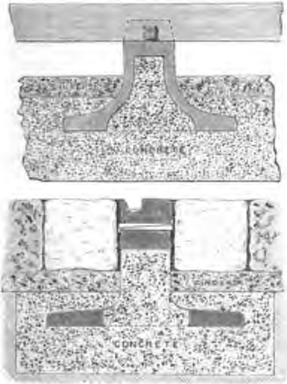
		£	s.	d.	£	s.	d.
Steel rails, 50 lbs. per yard, 78½ tons	@	7	10	0	588	15	0
3,520 cast-iron chairs, 103 tons	,,	5	0	0	515	0	0
4,000 wrought-iron keys, 9½ cwt.	,,	0	15	0	7	2	6
220 wrought-iron tie rods	,,	0	3	6	38	10	0
Excavation, 1,715 cubic yards, including carting away surplus material and maintenance of tramway for six months	,,	0	2	0	171	10	0
Lias lime concrete, 909 cubic yards	,,	0	7	6	340	17	6
Bed of gravel, 1½ inches thick, as spread, 200 cubic yards	,,	0	3	0	20	0	0
Laying the way, including fencing, watching, and lighting, 1,760 lineal yards	,,	0	1	6	132	0	0
Total for the way					1,823	15	0
Providing and laying granite paving sets, including ramming and grouting, and making good at sides of paving, 4,400 square yards	,,	0	10	0	2,200	0	0
					£4,023	15	0

KINCAID'S SYSTEM, NEWCASTLE-UPON-TYNE TRAMWAYS, 1878.

The first tramway in Newcastle-upon-Tyne was laid on Mr. Kincaid's system, to a gauge of 4 feet 8½ inches, under the direction of Mr. A. M. Fowler, the borough engineer, similar to the first ways laid by him at Salford. The way was laid early in 1878 for a length of five miles, of which about three miles were of double line and the remainder of single line. The rails weighed 50 lbs. per yard, and are of the same section as those of the Salford line. The cost of the way per mile, single line, amounted to £1,540 per mile, in which were included the cost of everything except providing and laying down pavement.

KINCAID'S SYSTEM—SALFORD TRAMWAYS, 1879—80.

When Mr. A. M. Fowler settled the details of Mr. Kincaid's way for the Salford Tramways, the principal feature on which he laid stress was the direct-acting spike for fastening the rail to the sleepers, two of which were, from opposite sides, driven into a plug of ash in the upper part of the chair or stool. This fastening has been found, according to the report of Mr. A. Jacob, to give way by the breaking up of the wooden plugs by the wedging of the spikes, and their gradually becoming loose. In November, 1879, Mr. Jacob introduced a method of fastening in which a pair of soft iron cotters were substituted for the wood block and the spikes, shown in Figs. 86 and 87 The rails are punched for the



FIGS. 86 and 87. Kincaid's Way, Salford, as laid by Mr. Jacob.—Rail and Chair—Sections. Scale ¼.

cotters, and square holes are very truly formed in the chairs. The lower cotter is inserted when the rail is placed in position, and the upper cotter is driven home, so that the rail is pinched tightly down to the chair. When the cotters have been tightly driven in, their ends, being of very soft iron, are easily turned over, one upwards, the other downwards. A small allowance for longitudinal play is made in the holes, to admit of free expansion.

Under the chairs Mr. Jacob laid a continuous bed of concrete, under each rail, along the whole line, and 6 inches deep, in which the bases of the chair are embedded. A good support is thus provided for the intermediate paving next the rails. The sets are now supported by the concrete, on a layer of cinders, for a depth varying according to the height of the sets. In the illustrations 5-inch sets are shown, resting on a cinder bed 1¼ inches thick.

The Welsh sets formerly used had been laid ¾ inch above the level of the rails, to make allowance for wear. But, in fact, they did not wear much faster than the rails; so they caused great inconvenience and gave rise to loud complaints of damage to wheeled vehicles. Scoriæ blocks, made from blast furnace slag, were substituted for the Welsh sets, and were laid next the rails, and level with them. They wear well and evenly, worn grooves were obviated, and complaints ceased.

In the Kincaid way, recently constructed in Salford, Figs. 86 and 87, the rails were of iron, faced with steel to take the wear, rolled in lengths of 24 feet. The cost was not much increased by the facing, and the duration of the rails was expected to be much augmented. By measurements made in Salford, Mr. Jacob ascertained that where the traffic on the old rails had been very heavy, as in New Bailey Street, 1/16 inch in thickness had been worn off the tread of the rails, being at the rate of ·025, or 1/40 inch per year. At this rate he estimated a life of 19 or 20 years for the rails, allowing for ½ inch of vertical wear before the rails required to be renewed. The rails were of box pattern, 3½ inches wide and 2⅝ inches deep, weighing 52 lbs. per yard. The tread is 1⅞ inches wide, the groove 1⅛ inches, and the guard flange

½ inch wide. The chairs were placed 3 feet from centre to centre. They are 7½ inches high, the soles are 14 inches square, and the length of bearing for the rails is 3 inches for the intermediate chairs, and 10 inches for the joint chairs. The joint chairs weigh 54¾ lbs. each, the intermediate chairs 45¼ lbs. each. The rails are fastened with one pair of cotters to the intermediate chairs, and with four pairs, two to each rail, to the joint chairs. The cotters were ⅜ inch wide. The chairs were hollowed, and were solidly packed with concrete. They were embedded in the concrete, which is laid in two continuous lines, one under each rail, 18 inches wide and 6 inches deep. Next comes a 1-inch layer of sand, and 5-inch paving upon this, with pitch grouting. Mr. Kincaid's way, as laid by Mr. Jacob in the manner above described, gave, it was reported, satisfaction. The first section, without the cotters, was opened March 18, 1879; with the cotters complete, the next section was opened May 12, 1880.

QUANTITIES AND COSTS OF TRAMWAYS, LAID IN SALFORD, PER MILE, SINGLE LINE, UNDER CONTRACTS NO. 5 AND 6, DATED DECEMBER 27, 1879.

		£	s.	d.	£	s.	d.
Steel-faced iron rails, 52 lbs. per yard, 81 tons 14 cwt. 1 qr. 4 lbs. . . .	@	8	5	0	674	2	10
Cast-iron chairs, 73 tons 6 cwt. 1 qr. 10 lbs.	,,	5	2	0	373	17	0
Cotters, 17 cwt. 1 qr. 4 lbs.	,,	1	3	0	19	17	0
Excavation in trenches, 587 cubic yards .	,,	0	15	0	384	15	0
Excavating roadway, taken up 6 inches in depth, for a total width of 18 inches outside the rails	,,	0	2	0	58	14	0
Laying single line, complete, 1,760 lineal years @	,,	0	0	11	80	13	4
					1,636	16	2
Paving with Welsh cyanite sets, including cinder bed and pitch grouting, 4,302 yards	,,	0	12	0	2,581	16	0
					4,218	12	2

NOTE.—The costs of slag blocks and granite sets are nearly equal.

KINCAID'S SYSTEM (AS LAID BY MESSRS. GROVER AND NEWTON), STOCKTON-ON-TEES AND DISTRICT TRAMWAYS, 1881.

The Stockton-on-Tees Tramways, 4⅜ miles in length, single line, including passing-places, were (May, 1881) in course of construction, to a gauge of 4 feet, under the direction of Messrs. J. W. Grover and J. W. Newton, the engineers of the line. They adopted the Kincaid system of way, in the recent form, slightly modified. The rails, of Bessemer steel, weighed 45 lbs. per yard, and were rolled in lengths of 23 feet, except 5 per cent. of shorter lengths. They are, like the Barker rail, indented on the lower side of the head, and formed with a central web. The chairs give a bearing 6 inches long, for the sole of the rail, and 3 inches at the sides. The rails are fastened to each chair by a cotter of Lowmoor iron, through the rail, transversely. The sole of each chair is 2 feet 10½ inches long, and 9 inches wide—wide enough to afford support for the paving. The total height of the chairs is $5\frac{13}{16}$ inches. The chairs are 1½ inches apart at the ends, and thus make up a distance of 3 feet apart between centres. But, at the joints, the chairs are placed not under the joint, but 2 feet apart between the centres, and are shorter accordingly. The joint is made with $\frac{9}{16}$-inch wrought-iron fish-plates, 13½ inches long, and four ¾-inch bolts and nuts, with Grover's elastic washers. The fish-plates are about 4 inches deep, underlapping the rails.

The rails are 1⅝ inches wide at the tread, 1 inch at the groove, with a ⅜-inch guard flange; together 3 inches. The groove is ⅞ inch deep, the web is ½ inch at the lower edge, and the total depth of the rail is $3\frac{13}{16}$ inches.

Cross-ties, of 2-inch angle-iron, are placed at 9 feet intervals, except in curves, at 6 feet intervals; passing under and seizing the chairs by means of clips, the outer clips being riveted to the angle-irons, and the inner clips bolted to them.

The trench was excavated to a depth of 12 inches below the surface, for a width of about 7 feet 3 inches, and was laid with concrete 5½ inches thick, consisting of 1 part of Portland cement in 7, or one part of lime in 4. The excavated macadam, after having been screened, was mixed with river sand, and occasionally with burnt clinkers. The sleepers were laid on this bed of concrete, after which the contour of the bottom was formed with a thin layer of fine concrete, and the spaces under the rails were filled flush with Portland cement concrete. On a ½-inch layer of furnace ashes the paving sets are laid, consisting of whinstone, 5 inches deep by 4 inches, toothing with the macadam at each side. The paving was grouted with lime mortar, and finished with a coating of furnace ashes.

QUANTITIES PER MILE, SINGLE LINE, OF KINCAID'S SYSTEM, STOCKTON-ON-TEES AND DISTRICT TRAMWAYS, 1881.

Steel rails, 45 lbs. per yard	70¾ tons
Cast-iron chairs—920 joint chairs 55 lbs. each	
2,760 intermediate do., 65 lbs. each	
3,680	102¾ ,,
Fish-plates, 920, @ 7⅝ lbs. each	2 ,,
Angle-iron ties, 612, @ 19¾ lbs. each	5½ ,,
Clips, 2,448; and rivets, 1,224	17 cwt.
¾-inch bolts and nuts, for fish-plates	11 ,,
⅝-inch bolts and nuts, for clips	5 ,,
Total	182 tons 13 cwt.

Grover's spring washers for ¾-inch bolts, 1,840
Do. do. do. ⅝ do. 1,224
Wrought-iron cotters, 3,680.
Excavation, 1,450 cubic yards.
Lime concrete, 770 ,, ,,
Bed of sand, or furnace ashes, 112 cubic yards.
Portland cement, or asphalte, filling under the rails.
Whinstone paving, laid complete, 3,960 square yards.
Laying the way, complete, 1,760 lineal yards.

CHAPTER XVI.

BARKER'S SYSTEM.—MANCHESTER CORPORATION TRAMWAYS, 1877.

THE first contract for the Manchester Corporation Tramways was completed on the 8th of May, 1877, and opened on the 12th of the same month. It consisted of three sections as follows:—

1. Lower King Street, Bridge Street; leading to Salford and Pendleton.
2. Deansgate; terminus in Manchester.
3. Hunt's Bank. Bury New Road, to the City boundary; leading to Higher Broughton.

The total length is 2 miles, comprising half a mile of double way and 1½ miles of single way, with six passing places. The maximum gradient on the line is at the rate of 1 in 40. After six months of working the line in Bury New Road, it was found that it could not be worked with advantage as a single line, and it was proposed to lay a second line of tramway in that road on Barker's system. The application of this system was to be extended to other lines under the control of the Manchester Corporation. The system was adopted also for the lines of tramway at Patricroft, and for lines to Newton Heath, Levenshulme, Openshaw, and other places.

The Manchester lines were constructed under the superintendence of Mr. J. H. Lynde, C.E., on the system of iron way shown in Figs. 88 and 89, patented in March, 1876, by Mr. Benjamin Barker. The peculiar features of this system are the longitudinal cast-iron sleepers, which afford a continuous bearing for the rail, and for the adjoining paving sets; and the grooved rail, of which the lower surface is indented longitudinally, and is formed with a central flange or web, by which it is fastened by cotters to the sleeper. The sleeper is, in section, like the ordinary bridge-rail in use on railways, but it is of larger dimensions. It consists of a hollow vertical portion, 3 inches wide, furnished with a solid head, formed to fit and to carry the rail, and two horizontal flanges, about 4 or 4½ inches wide, making in all a broad continuous base 12 inches in width. The total height of the combined sleeper and rail is 7⅝ inches, and the clear height above the flange-base is 6⅞ inches, leaving a ⅞-inch space for bedding under the paving sets, which are 6 inches deep, and adjoin the rail. The sleepers are cast in lengths of 2 feet 11⅛ inches, and are stiffened by two transverse webs between the vertical ribs. The thickness of metal of the sleepers is ½ inch, except for the flanges, which are made ⅝ inch thick at their roots, next the vertical ribs, and taper in thickness to ⅜ inch at their edges; except also the head of the sleeper, which is sufficiently massed to provide a solid bearing and attach-

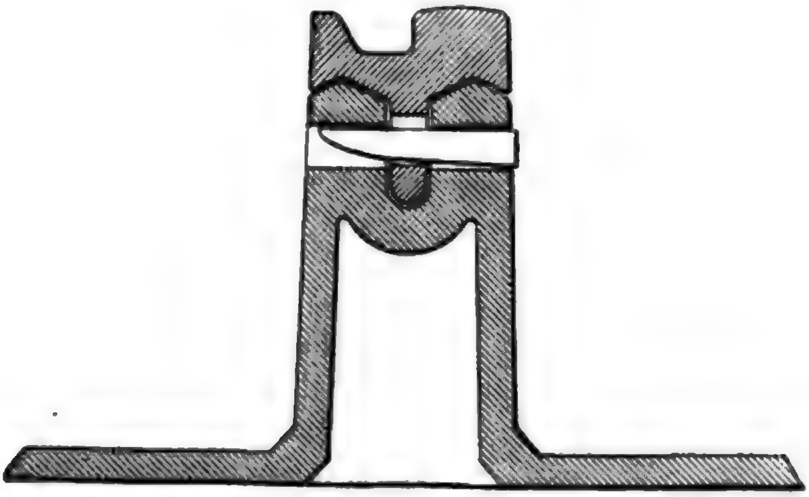


FIG. 88. Manchester Corporation Tramways:—Section of Rail and Sleeper. Scale ¼.

ment for the rail, and a vertical wall at each side, as an abutment for the stone sets. The castings were made from remelted iron, containing at least ⅙th part of scrap. Two test bars were cast each day that any of the castings were run, 1 inch wide, 2 inches deep, and 3 feet 6 inches long; one of which was tested edgewise on bearings, 3 feet apart, and was not to break with any weight less than 27 cwt. applied at the middle. If the test-bar failed to sustain the test, all work cast from the same melting was rejected. Each sleeper, 2 feet 11½ inches in length, was to weigh not less than 137 lbs.; or for a length reckoned as 3 feet, at the rate of 137 lbs. per lineal yard. The position of the holes for the keys, cast in the sleepers, was not to vary more than 1/16 inch from the given position.

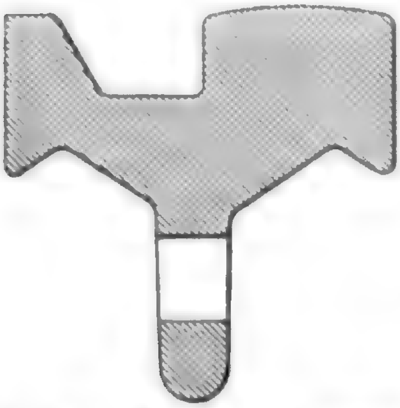


FIG. 89. Manchester Corporation Tramways:—Section of Barker's Rail. Scale ½.

The rails were rolled of Bessemer steel, 3 inches wide, and weighed 40 lbs. per yard. They were rolled in lengths of 18, 21, and 24 feet. The tread or rolling surface of the rails is 1¼ inches wide, and is rounded with nearly ⅛ inch of rise; the groove is 1⅛ inches wide, and 11/16 inch deep below the summit of the tread. The side of the groove next the rail is vertical, the bottom of the groove is ¾ inch wide, and the whole of the taper of the groove is directed towards the ledge. The lower side of the rail is longitudinally indented, and is strongly formed with inclined flanks, from which the central web depends. The web is ½ inch thick, and the total depth of the rail amounts to 3 inches. The indentations of the rail fit on the corresponding wedge-formed surfaces of the head of the sleepers; and the rail is fastened to the sleepers by horizontal cotters of hard wrought iron, ½ inch by ⅜ inch, slightly taper, which pass right through the flange of the rail and the head of the sleeper. There is one cotter to each sleeper, except at the joints of the rails, where there is one cotter extra for each end. By this method of attachment the rail is secured by the indented surfaces against lateral displacement, whilst the chief function of the cotter is to hold it down to the sleeper.

It was required that the rails should be manufactured from a mixture of the best English hematite brands and spiegeleisen, cast into ingots of sufficient weight to make one or more rails. The curved rails were bent, cold, in a bending machine to the required radii. The flanges of the rails were punched for the cotter holes, and the holes were required to be within 1/16 inch of the proper position.

The way was laid to a gauge of 4 feet 8½ inches, with an interspace 4 feet wide between the two lines of a double way. The new pavement is not confined to the customary breadth of 18 inches outside the ways, but is in some cases laid for the whole width of the carriage way to render the whole of the surface uniform. Allowing for purposes of comparison the usual 18-inch breadths of paving outside the ways, the total width for a double way is made up thus :—

	Ft.	Ins.
Two widths of gauge, 4 feet 8½ inches	9	5
Interspace	4	0
Two breadths of 18 inches	3	0
Four half-widths of rail (1½ inches × 4)	0	6
	16	11

The sleepers are not fastened together, but are fastened ½ inch apart from end to end, and make up intervals of 3 feet for each straight sleeper. For sharp curves the sleepers are laid in shorter segments 18 inches in length. Sleepers have been cast to match curves in some instances, but, it is said, it was not necessary to provide sleepers of a curved form.

The roadway was excavated to a uniform depth of about 8 inches. The bottom of the excavation was taken as the foundation for the sleepers, as the ground was considered to be sufficiently consolidated to support the tramway with its extensive bearing surface without the assistance of special concrete foundations. The sleepers were, nevertheless, for the purpose of packing, bedded on a 1-inch layer of rough mortar. Before being laid they were filled with rough mortar. The mortar was composed of three parts of clinker and one part of Ardwick (hydraulic) lime, ground in a mill.

The rails were bedded on the sleepers in gas tar, which aids in filling up any chance vacancies between the sleepers and the rails. The flat rails, without grooves, were only laid, as outer rails, at one curve of the way, having a radius of 32 feet.

The paving is of granite sets, 3 inches wide and 6 inches deep, laid on a 2-inch bedding of small gravel or old macadam. The joints were filled in with pea-gravel, or small granite chips, and grouted with a boiling mixture of pitch and creosote, on the system which has for years been practised in laying pavement in Manchester.*

The contractors were required to replace any sleepers or rails found to be defective for a period of twelve months after the work was completed. Payments were made at intervals to the extent of 80 per cent. of the value of the work executed; the balance was payable at the expiration of three months after the completion of the work.

In one mile, single line, of Mr. Barker's system of tramway, as laid in Manchester, there are 215 tons of cast-iron sleepers and 63 tons of steel rails. Of the mortar bedding for the sleepers 40 tons per mile was used. The price of the rails, delivered, was £8 per ton, and that of the sleepers was £5 4s. 6d. per ton. The mortar bedding cost 7s. 6d. per ton, delivered on the ground. The total cost for materials and labour, to remove the old paving, prepare the bed for the sleepers with a layer of rough mortar 1 inch thick, and lay in the tramway complete (exclusive of all charge for paving), was £2,320 per mile, single line. The annexed is a cost list comprising the items of cost in a tabular form:—

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* For an account of the Manchester system of paving, see *Construction of Streets and Roads*, 1877. Crosby Lockwood & Son.

MANCHESTER CORPORATION TRAMWAYS, BARKER'S SYSTEM, COST PER MILE, SINGLE LINE.

		£	s.	d.	£	s.	d.
215 tons cast-iron sleepers	@	5	4	6	1,123	7	6
63 tons steel rails, 40 lbs. per yard	,,	8	0	0	504	0	0
1,760 lineal yards, labour, mortar bed, and royalty	,,	0	7	3	638	0	0
Wedge keys					25	0	0
Carting the materials (iron only)					29	12	6
Cost of way					2,320	0	0
4,400 square yards of paving	,,	0	12	0	2,640	0	0
Total					£4,960	0	0

At Leeds, in 1878, about 4 miles of Barker's tramways were laid, of three different sections: 1st, the section for 6-inch paving, having a rail of 40 lbs. per yard and sleepers of 137 lbs.; 2nd, the section for 5-inch paving, with sleepers of 102 lbs. and rails of 34 lbs. per yard; 3rd, the section for 4-inch paving, with sleepers of 90 lbs. and steel rails of 34 lbs.

In the Barton, Eccles, Winton, and Monton district, at Patricroft, near Manchester, Barker's system was, in 1878, laid for a length of 3½ miles, with 40-lb. steel rails and 135-lb. sleepers for 6-inch paving. The line of tramway cost about £4,000 per mile. The total cost for construction and all incidental charges amounted to £17,200. The tramway was leased to Messrs. Turton and Busby.

At Wallasey, near Liverpool, a line of about 4 miles in length was laid, in 1879, for 4-inch paving, with 34-lb. steel rails and 90-lb. sleepers. This line was laid by the engineer of the tramway, Mr. C. H. Beloe, who states the cost per mile, single line, as follows:—

	£	s.	d.
Laying tramway rails, concrete, &c.	2,031	6	8
4-inch granite cubes	1,144	0	0
Paving	608	13	4
Total	£3,784	0	0

SHAW'S SYSTEM.—RUSHOLME, MANCHESTER, 1880.

This is a metal way, in which the rails are laid on chairs or stools, which are cast solid in pairs upon long cast-iron sleepers. The rails are spiked to the stools.

Mr. J. C. Shaw's system is here illustrated, Figs. 90 and 91, as laid at Rusholme. The cast-iron sleepers are made in lengths of 4 feet, and 11 inches wide at the base, laid 1 inch apart longitudinally. Each sleeper is formed with two standards or pedestals to carry the rail, placed at 2 feet 6 inches apart between centres, or about half the length of the sleeper. The middle portion of the sleeper, between the standards, is open, and is bordered with two stiffening flanges. Each sleeper weighs 117 lbs. The rails, of steel, weigh 45 lbs. per yard, and are of the ordinary box section, 3 inches wide, through the side flanges of which they are spiked to the standards, into which hardwood plugs are driven to receive the spikes, one spike from each side, as in Mr. Kincaid's early fastening. To the joint standards the end of each rail is secured by two pairs of spikes; at the intermediate standards one pair of spikes

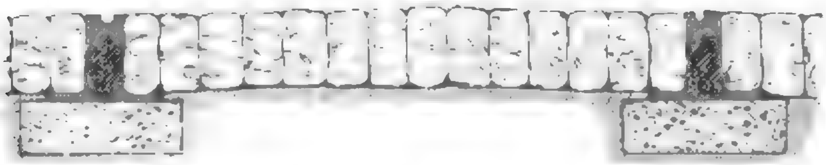


FIG. 90. Shaw's Way, Rusholme. Scale $\frac{1}{24}$.

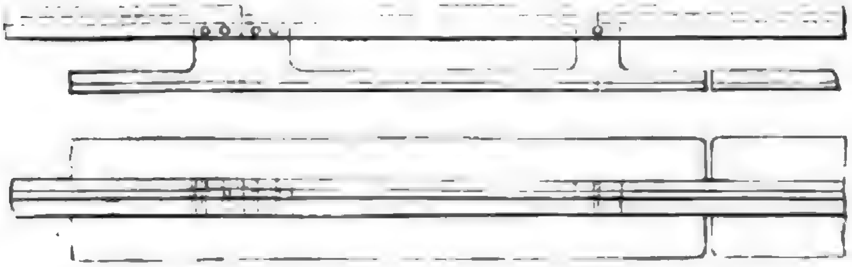


FIG. 91. Shaw's Way, Rusholme.—Rail and Sleeper. Scale $\frac{1}{24}$.

is employed. The length of bearing of the rails on the joint standards is 9 inches, and on the other standards 4¾ inches. It is stated that the rails have been tested with a load of 7 tons at the centre of a span without any perceptible deflection. The sleepers are bedded on two continuous lines of concrete, 15 inches wide and 5 inches deep, one under each line of sleepers. The spaces under the sleepers are completely filled with fine concrete, which is packed upon the basement of concrete through the openings in the soles of the sleepers, and so bonding the sleepers to the beds.

The general level of the floor of the excavation, excepting the trenches, is 8 inches below the surface of the ground, as the paving sets are laid direct on the subsoil. The paving adjacent to the rails is supported directly on the base of the sleepers.

QUANTITIES AND COSTS OF SHAW'S WAY, PER MILE SINGLE LINE, 1880.

		£	s.	d.
Rails, 45 lbs. per yard, 70 tons	@ £11	770	0	0
Sleepers, 70 lbs. per yard, 110 tons . .	,, £5 5s.	577	10	0
Spokes, 14 cwt.	,, 18s.	12	12	0
Wooden plugs, 6,160	,, ½d.	12	14	0
Concrete, 204 cubic yards	,, 16s. 6d.	168	16	0
Excavation, 204 cubic yards	,, 2s.	20	8	0
Surface excavation, 8 inches deep, 1,109 cubic yards	,, 2s.	110	18	0
Total cost of way		1,672	18	0
Paving, 4,694 square yards	,, 11s. 6d.	2,699	0	0
Total cost of way and paving . .		£4,371	18	0

CHAPTER XVII.

DOWSON'S IRON WAY.

MESSRS. J. E. and A. Dowson devised a system of iron permanent way, with continuous bearing, in various forms, patented in 1871 and in March, 1873. The Madras tramways, consisting of 11 miles of single line, to a gauge of 1 metre, opened in 1874, were constructed according to one of the forms patented in 1873, Fig. 92. The rail was of wrought iron, an ordinary flat-grooved rail. It was laid on a series of cast-iron sleepers, which overlapped laterally at the ends, where they were bolted together, and afforded a continued bearing for the rail. The sleepers were formed with fitting strips, by which they were levelled to receive the rail, and the fastenings consisted of vertical bolts with countersunk heads, through the groove of the rail, cottered to the sleepers.

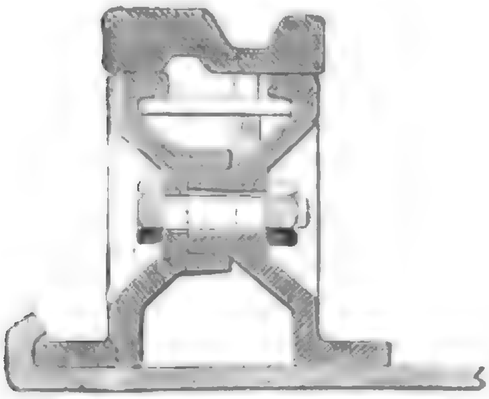


FIG. 92. Dowson's Iron Way.—Madras Tramways. Scale ¼.

The rails were 1 inch thick and 3¾ inches wide; they weighed 26 lbs. per yard. The sleepers weighed 40 lbs. per yard, as laid; they were 2 feet in length, of a flanged form, 4½ inches deep and 2 inches wide. The width of bearing surface on the foundation, which was of concrete, amounted to 4 inches. The sleepers were tied transversely with hook tie bars at intervals.

CHAPTER XVIII.

WINBY AND LEVICK'S SYSTEM.

NOTTINGHAM AND DISTRICT TRAMWAYS, 1878.

IN December, 1877, Mr. Levick and Mr. F. C. Winby patented the application of a broad base of iron plate, fastened to the lower flange of the girder rail, by means of cotter bolts and cotters, to be laid on consolidated macadam or road material, in order to make up a sufficient foundation without concrete, and to give support to the pavement.

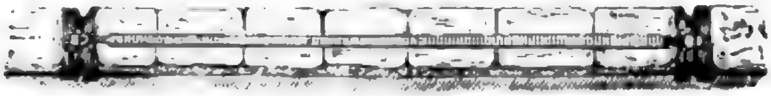


FIG. 93. Winby and Levick's Way, Nottingham. Scale $\frac{1}{24}$.

The length of lines of the Nottingham and District Tramways, laid by Mr. T. F. McNay, on the system of Messrs. Winby and Levick, Fig. 93, by Messrs. Ridley & Co., of Newcastle-upon-Tyne, consists of 4 miles 246 yards double line, and 2 miles 1,012 yards of single line; together 6 miles 1,258 yards, making 10 miles 1,504 yards of single line. The rail, Fig. 94, is of steel, 6 inches deep, weighing 58 lbs. per yard. The width of the tread is 1⅝ inches, that of the groove is ⅞ inch, and the guard flange is ⅜ inch thick, making the total width of the head 2⅞ inches. The flange base is 3½ inches wide, and the web is ⅜ inch thick. The base plate is of wrought iron 12 inches wide and ¼ inch thick, in lengths of 11 feet 11 inches, laid continuously, and so as to break joint with the rails. The rails are secured to the base-plate by ¾-inch cotter bolts and cotters, at intervals of 2 feet, on alternate sides of the rails. The gauge is fixed by means of tie-bars, 1¼ inches deep and ⅜ inch thick, having screwed ends ¾ inch in diameter, and lock-nuts through the web of the rails, placed 12 feet apart. The rails are in lengths of 24 feet and are fished with steel plates, 16 inches long, and four ¾ inch bolts and nuts.

The contract for the rails, plates, and fastening, laid complete, was let to Messrs. Ridley and Company at £2,000 per mile, single line, inclusive of the extra material and labour for points and crossings and curves. The items in detail are here given as stated by the contractors. In the last two columns are added, by the author, the estimated net quantities and costs per mile, single line, exclusive of such extras :—

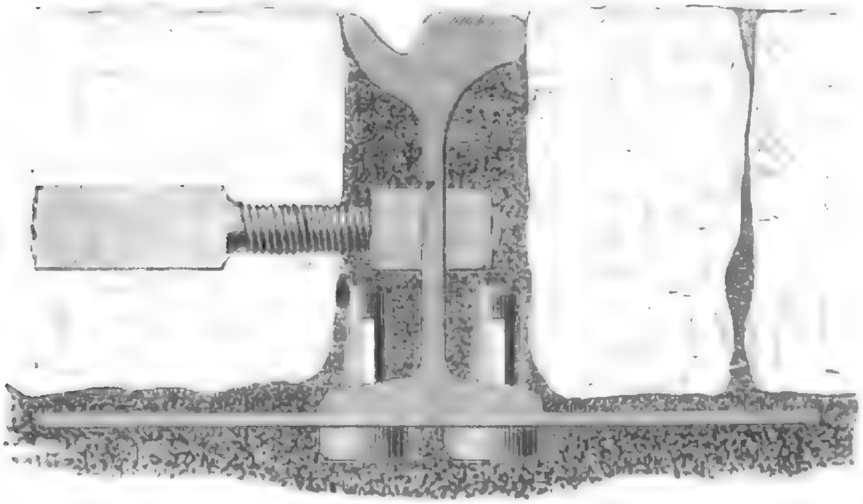


FIG. 94. Winby and Levick's Way, Nottingham.—Rail and Baseplate. Scale ¼.

QUANTITIES AND COSTS PER MILE, SINGLE LINE, OF WINBY AND LEVICK'S SYSTEM.—NOTTINGHAM AND DISTRICT TRAMWAYS, 1878.

	Gross weight.		Gross cost. £	Net weight.	Net cost. £
Steel rails, 58 lbs. per yard . .	92 tons	@ £10 10s.	966	91 tons	956
Wrought-iron base-plates 12 in. × ¼ in.	50 ,,	,, £8	400	47 ,,	376
Fish-plates . .	5 ,,		150	6 ,,	120
Fish-bolts . .	0·75 ,,				
Cotter-bolts and cotters . . .	1·75 ,,				
Tie-bars . . .	1·75 ,,				
	149·25		1,516	144	1,452
Excavation, 4,694 square yards		,, 1s. 6d.	353		353
Laying 1,760 lineal yards .		,, 1s. 6d.	132		132
Total cost for way . .			2,001		1,937
Paving by the Tramway Company, 4,858 square yards .		,, 10s. 6d.	2,550		2,550
Total for way and paving			£4,551		£4,487

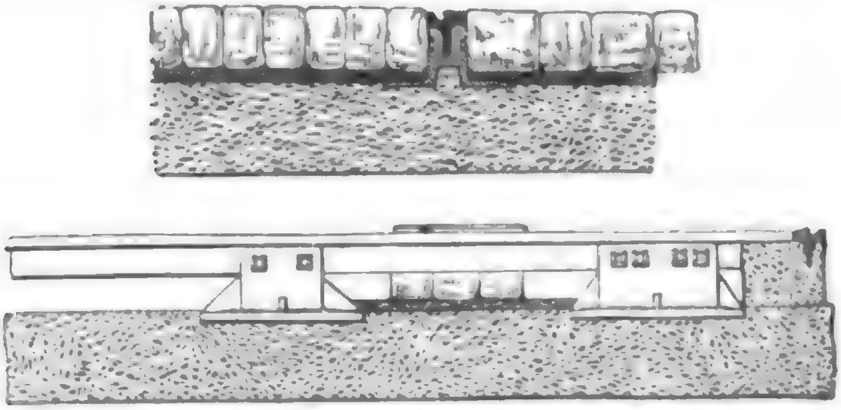
NEWCASTLE-UPON-TYNE, 1879.

A length of 5 miles 6¼ chains, of Winby and Levick's way, was laid in Newcastle by Messrs. Ridley and Co., in 1879—80, to a gauge of 4 feet 8½ inches. Of this length, about 2 miles was double way and 3 miles single way. The rails weighed 65 lbs. per yard. The base-plates are 12 inches wide and ⅜ inch thick. With fish-plates and tie-rods the gross weight of material, inclusive of points and crossings, was 181 tons per mile, single line; and the cost, including the charge for laying, amounted to £1 4s. 1d. per yard, or £2,119 per mile, single line, paving not included.

CHAPTER XIX.

WILSON'S SYSTEM.—SOUTHAMPTON STREET TRAMWAYS, 1878.

Mr. Edward Wilson, the engineer of the Southampton Street Tramways, on a gauge of 4 feet 8½ inches, arranged an adaptation of the central web rail, Figs. 95 and 96, with cast-iron chairs, resembling in cross section Barker's sleepers, laid on concrete. The rails, Fig. 97, are of Bessemer steel, weighing 55 lbs. per yard, in ruling lengths of 24 feet. The head of the rail is 1¾ inches wide, the groove is 1⅛ inches wide at the surface, and the guard-flange, though it is something more massive than a flange is supposed to be, is ⅝ inch wide at the surface, making altogether a width of 3½ inches. The depth of the rail is 3$\frac{15}{16}$ inches. The flange is tapered to $\frac{9}{16}$ inch in thickness at the lower edge. The rail takes a square bearing on the chair.



Figs. 95 and 96. Wilson's Way, Southampton. Scale $\frac{1}{24}$.

The joint chairs, Fig. 98, weigh 66 lbs. each, and the intermediate chairs 58 lbs. each ; the soles of all the chairs are 12 inches wide and 16 inches long, and the total height of the chairs is 5½ inches. The length of seat for the rails is 11 inches in the joint-chairs and 8 inches in the others. The chairs are placed at 3 feet distance from centre to centre, and are fastened to the rails with two steel cotters intermediately, and four cotters at the joints ; the cotters are 3 inches long, 7/16 inch thick and taper. The chairs are tied to gauge transversely by wrought-iron tie-bars 1½ inches deep by ⅜ inch thick ; these are let into recesses cast in the chairs, and being notched on the lower side, are dropped upon a corresponding elevation on the bottom of each recess, then secured in position by keys.

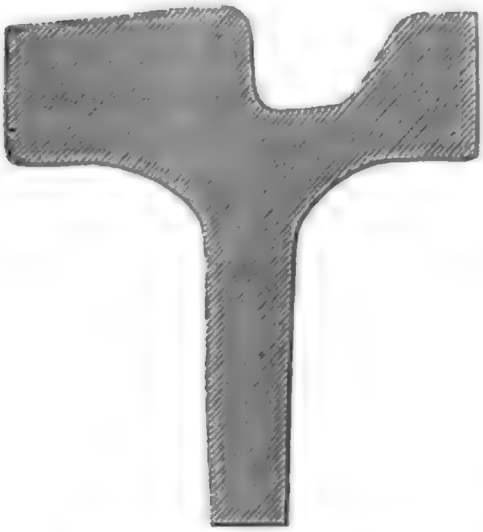


FIG. 97. Wilson's Way, Southampton.—Rail. Scale ½.

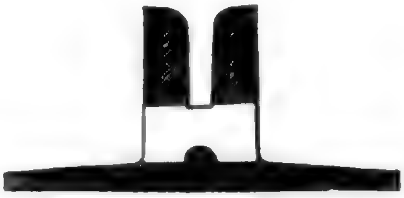


FIG. 98. Wilson's Way, Southampton.—Section of Chair. Scale ⅛.

A trench 8 feet wide was excavated for one line of rails, to a uniform depth of 15 inches for the routes of heavy city traffic, and 10½ inches for the routes of light traffic, increased to 15 inches under the rails for a width of 22 inches under each rail, forming trenches there. A bed of concrete, 9 inches deep, is laid in the heavy routes, for the whole width, and in the trenches only for the light routes. In the shallower portions of the excavation for the light routes the concrete is laid 4½ inches deep, making up a flush surface for the paving. The soles of the chairs are let flush into the concrete, and uniformly bedded on a thin layer of cement. The concrete is composed of 5 parts of clean sharp gravel, or of stones broken to a 1-inch gauge, 2 parts of clean sharp sand, and 1 part of Portland cement, weighing not less than 110 lbs. per striked bushel.

The space between the rails is closely filled with fine Portland cement concrete in the proportion of 4 parts of fine gravel to 1 part of cement.

A layer of sand, 1 inch thick, was laid on the concrete to bed the paving sets. The sets are of granite, from 3½ inches to 4 inches wide; those next the rails are 6 inches deep, of blue Guernsey granite; the others are 5 inches deep, of Welsh or Cornish granite. The paving was grouted with liquid mortar made with six parts of fine sand and one part of lias lime. It was laid ¼ inch above the level of the rails. A portion of the work is paved with wood.

QUANTITIES PER MILE, SINGLE LINE, OF WILSON'S WAY, SOUTHAMPTON STREET TRAMWAYS, 1878.

Routes of Heavy City Traffic:—

Rails, 55 lbs. per yard	86·4 tons.
Chairs, 3,070 single, 450 joints	93·8 ,,
Tie-bars	3·5 ,,
Keys and cotters	1·6 ,,
Excavation	1,955·2 cubic yards.
Concrete	1,173·2 ,,
Cement filling under rails	50·6 ,,
Granite pitching	4,351 square yards.

CHAPTER XX.

DUGDALE'S SYSTEM.—HUDDERSFIELD CORPORATION TRAMWAYS (INNER CIRCLE), 1881.

THE metal system, Fig. 99, of Mr. R. S. Dugdale, the borough surveyor, adopted for the original tramways of Huddersfield, comprising 10 miles of single way, was laid to a gauge of 4 feet 7¾ inches, in order that railway waggons might be run over the lines to the suburban districts of the borough. As in the case of the Vale of Clyde Tramways, the waggons were designed to bear on their flanges, which take a bearing on the floors of the grooves; whilst, of course, the tramcars run, as usual, on the treads of the rails. For this double purpose, the section of the rails, Fig. 100, was specially designed to combine strength and durability; providing a sufficient thickness of metal and strength under the groove, where the principal load is to be taken, and a wedge-form bearing surface to rest on the sleepers, chairs, or bearers. The groove is 1¼ inches wide at the surface, and ¾ inch in depth; the tread is 1½ inches wide, the guard flange ½ inch wide; making the total width of rail 3¼ inches. The web is ⅜ inch thick at the lower edge, and the total depth of the rail is 3¼ inches. The rails are of steel, weighing 43 lbs. per yard, in

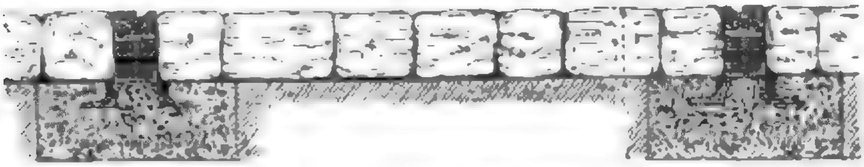


FIG. 99. Dugdale's Way, Huddersfield. Scale $\frac{1}{24}$.

lengths of 12, 15, 18, 22, 27, and 30 feet, of which 70 per cent. are 24 feet long. In the web of each rail, sixteen rectangular holes ¾ inch wide and ½ inch deep are punched, to receive the cotters; two holes near each end, to make the joint, and the others in couples, a couple for each intermediate bearer. The guard flange is corrugated, 14 indents to the foot. The bearers, of cast iron, shown to an enlarged scale, Fig. 101, weighing 80 lbs. each, are open or frame-like; and are formed with a sole 25 inches long, 10 inches wide, and ⅝ inch thick. The body, or upper part, is 18 inches in length, and the width of the rail is 3¼ inches. It stands 3 inches high, and the bearing surface is formed trough-like to lodge the rail securely. The base is hollowed out, and the vacuity opens into the hollow space in the body. One pattern of bearer is used for the joints and the intermediate supports, and each bearer is cast with six cotter holes. Eight bearers are laid for each 24 feet lengths of rail, and they are placed at uniform distances apart, 3 feet between centres. The rails are fastened to the joint bearers by four cotters, through the four inner holes, two to each end of the rails; and to the intermediate bearers by two cotters passed through the two extreme holes. The cotters, or "spikes," are of soft flat iron, ½ inch wide; they are double, with reverse taper, and are driven in from opposite sides, so as to wedge down

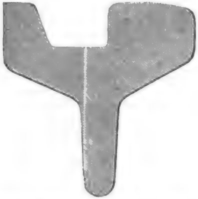


FIG. 100. Dugdale's Way, Huddersfield.—Rail. Scale ½.

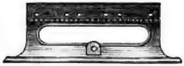


FIG. 101. Dugdale's Way, Huddersfield.—Bearer. Scale $\frac{1}{12}$.

the rail upon its seat. "Softening," a kind of tarred felt, in thin sheets, is placed, after having been gently heated, in the grooves of the bearers, so that all the bearing surfaces are covered with it, before the rails are placed, in order to absorb vibration.

The roadway was excavated to a depth of 6½ inches below the level of the rails, for the paving, and two trenches were cut, one under each rail, 18 inches wide, and 13½ inches below the level of the rails, to receive the two continuous beds of concrete, 7 inches deep. The concrete is composed of 4 parts of clean sharp gravel or broken stone to a 1½-inch ring gauge, and 1 part of best Portland cement. The bearers are embedded in the concrete for a depth of 2½ inches, the open spaces in the body of the bearers and between them under the rails are well packed with concrete, finished with vertical sides flush with the sides of the bearers.

The paving consists of granite sets, 6 inches deep, from Rossendale Valley, Yorkshire, bedded on a ½-inch layer of fine clean mill ashes. They are racked with fine granite chippings, and grouted with hot pitch.

QUANTITIES AND COSTS, PER MILE, SINGLE WAY, OF DUGDALE'S SYSTEM, HUDDERSFIELD CORPORATION TRAMWAYS, 1881.

		£	s.	d.	£	s.	d.
Bessemer steel rails, 43 lbs. per yard, 67·12 tons	@	7	12	6	511	7	3
Cast-iron bearers, 80 lbs. each, 125·70 tons	,,	4	1	0	509	2	10
Wrought-iron fastening spikes, 1 ton .	,,	16	18	6	16	18	6
Tarred felt softening, 1,760 lineal yards .	,,	0	0	1½	9	15	6
Taking up pavement or macadam for a width of 8 feet, cutting two trenches for concrete foundations, laying foundations, rails and bearers, ready for paving, including cartage for all materials, 1,760 lineal yards	@	0	4	9	418	0	0
Total for way . . .					1,465	14	1
Paving, 6 inches deep, 8 feet wide, complete, 1,760 lineal yards	@	0	16	9	1,474	0	0
Total for way and paving .					£2,939	14	1

In 1891—92, ten years after the first contract was let for the original line above described, the Huddersfield Tramways were reconstructed and extended, with steel girder rails. weighing 100 lbs. per lineal yard, as shown in Figs. 102 and 103. The rail is 7 inches high, 7 inches wide over the flange-base, with a $\frac{7}{16}$-inch web. The base is $\frac{3}{8}$ inch thick at the edges, $\frac{5}{8}$ inch near the web. The guard-fillet is $\frac{3}{4}$ inch wide at the surface. The rails are laid to the railway gauge, 4 feet 8½ inches, secured to gauge by wrought-iron tie-bars, 2 inches by ½ inch thick, fixed at from 9 feet to 12 feet apart, screwed for a nut and a jam-nut, $\frac{7}{8}$ inch in diameter at one end, and notched at the other end to lock with the web of the rail. The joints are fished with two steel flanged fish-plates (Dugdale and Pogson's patent) $\frac{7}{8}$ inch thick, 24 inches long, and six 1-inch bolts with self-locking nuts. The joint is, in addition, strengthened by means of a ½-inch iron sole-plate 12 inches wide, and equal in length to the fish-plates, screwed to the flanges of the rail and fish-plates with eight ¾-inch bolts and self-locking nuts. The rails are laid upon a continuous bed of strong cement concrete 7 inches deep, 8 feet wide. The space between the rails and for a width of 18 inches outside is paved with granite sets, the outer edge of the marginal pavement being serrated every two courses of sets.

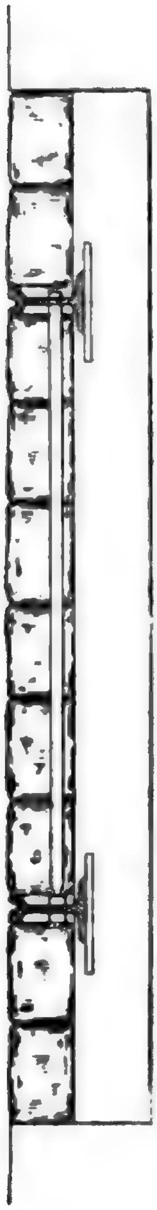


FIG. 102. Huddersfield Corporation Tramways: Cross Section of Way. Scale $\frac{1}{48}$

The lengths of the rails as manufactured were 24 feet, 26 feet, 28 feet, and 30 feet, of which 90 per cent. were 30 feet long. The number of 24-foot rails did not exceed 5 per cent. of the total number. The scheme of tests was as follows:—Take at least four pieces of rail 5 feet long, from each day's make, and place them on solid bearings 3½ feet apart, the ends to be securely fixed and properly bedded; to stand the following tests; 1st. By suspending a dead weight of 25 tons from the centre between the bearings; each sample to support this load for half an hour without exhibiting a greater deflection than $\frac{7}{16}$ inch, or any permanent set exceeding $\frac{3}{16}$ inch. 2nd. By a weight of 1,120 lbs. (10 cwt.) falling in proper guides upon the centre of each sample from a height of 20 feet without breakage of the sample. Each bolt was to be of the B B quality, and to be capable of resisting a tensile stress of 18 tons on a circular section 1 inch in diameter.

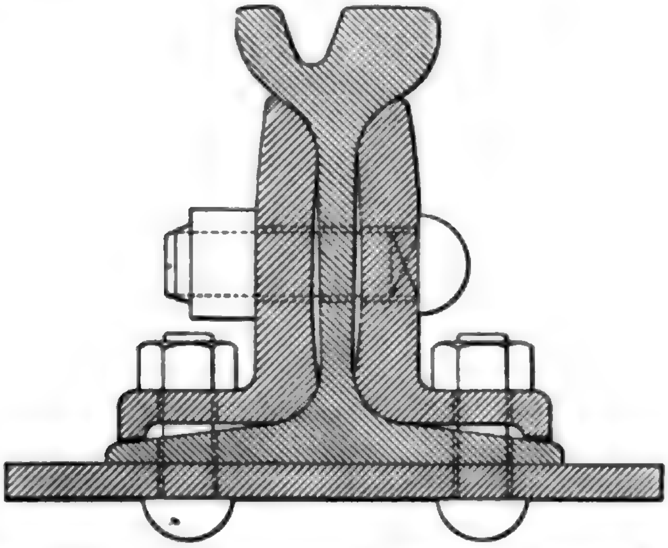


FIG. 103. **Huddersfield Corporation Tramways: Section of Rails and Fastenings. Scale ¼.**

Mr. Dugdale's most recent design of way, above described, is notable for the elaborate construction of the fish-joints, specially in order to secure strength and solidity at the junctions. The cost of construction of the way was about £4,000 per mile, single line.

CHAPTER XXI.

BRUNTON'S SYSTEM.—CITY OF OXFORD AND DISTRICT TRAMWAYS.

THE Oxford Tramways were laid to a gauge of 4 feet, with an interspace for double ways of 3 feet between the rails.

The rail, Fig. 104, was of Bessemer steel, weighing 67 lbs. per yard, of the Brunel rail, or bridge rail section, 4⅛ inches high, 3 inches wide at the surface, and 6¾ inches wide at the base, rolled to the standard length of 18 feet. The tread is 1½ inches wide, the groove 1 inch wide, and the guard flange ½ inch thick. The sides are $\frac{7}{16}$ inch thick, and the flange base ⅜ inch. The tread has a minimum depth of ⅞ inch. The rails are laid on cast-iron chairs at the joints, 9 inches long, and 8⅞ inches wide, consisting of a flat plate ⅞ inch thick; with raised edges between which the

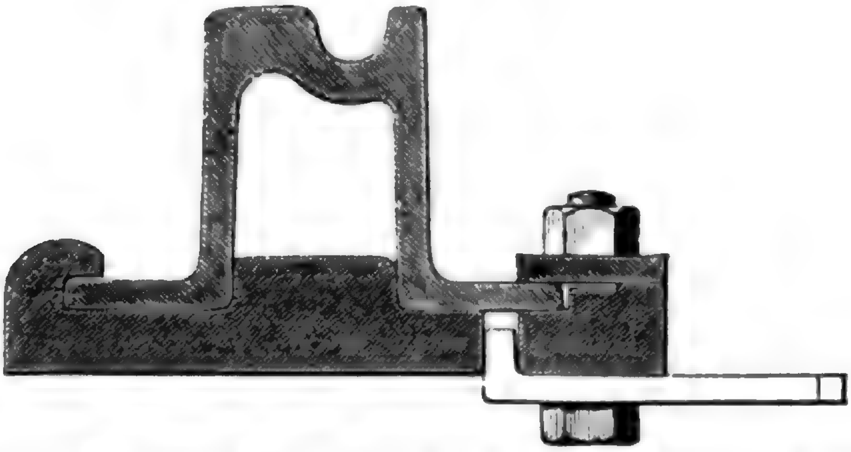
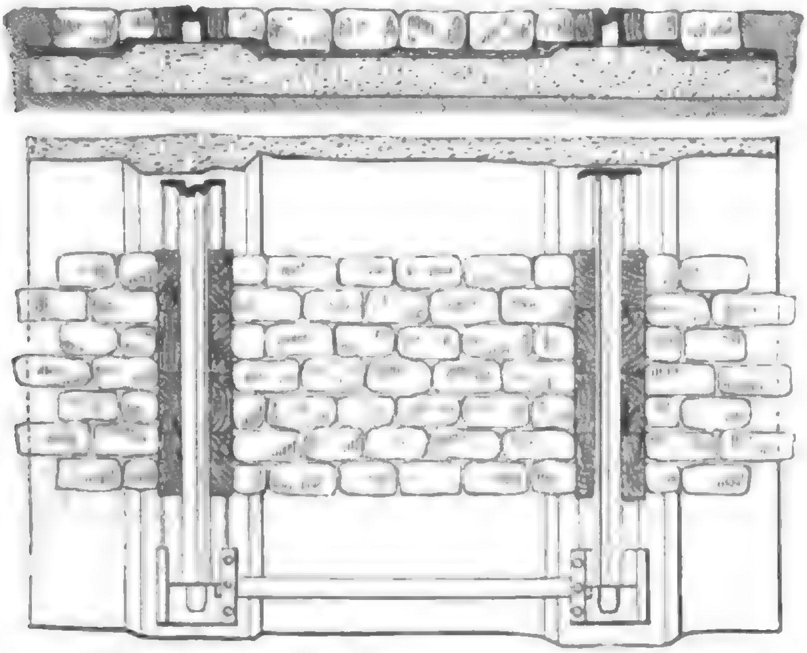


FIG. 104. Brunton's Way, Oxford.—Rail and Fastening. Scale ¼.

base of the rail is laid, and a central oblong stud, 2½ inches wide and 6 inches long, over which the ends of the rails are laid, and by which, like a key, they are kept in position, true to each other.

The rails are held and locked down by a wrought-iron fish-plate, of the same length as the chair, 2 inches wide and ⅜ inch thick, overlapping the flange of the rail, and fastened by three ¾-inch bolts and nuts to the chair. The nuts are Halpin's lock nuts; a gauge-tie, of bar-iron, 2 inches by ⅜ inch, having the ends turned up and passed into apertures cast in the chair, is fastened to each chair and its opposite neighbour by the middle one of the three bolts by which the fish-plates are fixed.



FIGS. 105 and 106. Brunton's Way, Oxford. Scale $\frac{1}{24}$.

The plan of the way is shown in Figs. 105 and 106. The ground is excavated to a depth of, say, 10 inches below the surface, for a width of 7 feet 3 inches for single lines, and 14½ feet for double lines. A bed of concrete is laid on the bottom of the excavation for the whole width 4½ inches deep; except at the rails, where it is made up to a depth of 6 inches. The concrete consists of one part of Portland cement, 2½ parts of clean sharp sand, and 5½ parts of gravel or broken stone. The paving is of granite, 5 inches deep. At each side of each rail, a longitudinal course of sets is laid, specially fitted closely and truly, and made to bed evenly on the flanges of the rails. This longitudinal paving may, as an alternative, be of wood,—Norway pitch pine. The paving is laid on a bed of sharp sand. The whole of the paving, except the longitudinal blocks next the rails, is to be thoroughly grouted with liquid mortar, composed of six parts of sand to one of fresh lias lime. Before the grout sets, the paving is rammed evenly with wooden beaters; after which the interstices are finally filled up with grout. The longitudinal blocks are not rammed. At the time of first grouting, above noticed, they are to be thoroughly grouted with thin cement mortar, composed of six parts of sand to one part of Portland cement, so as to completely fill up all the interstices below the blocks, or between them and the rail flanges, or the bed of concrete. The joints between the courses of the sets at the tie-bars are filled with fine gravel, or fine stone chippings, and grouted with thin cement mortar. All spaces between the sides of the paving and macadam or the soil are to be filled with gravel and macadam, and thoroughly rammed before the final grouting of the paving.

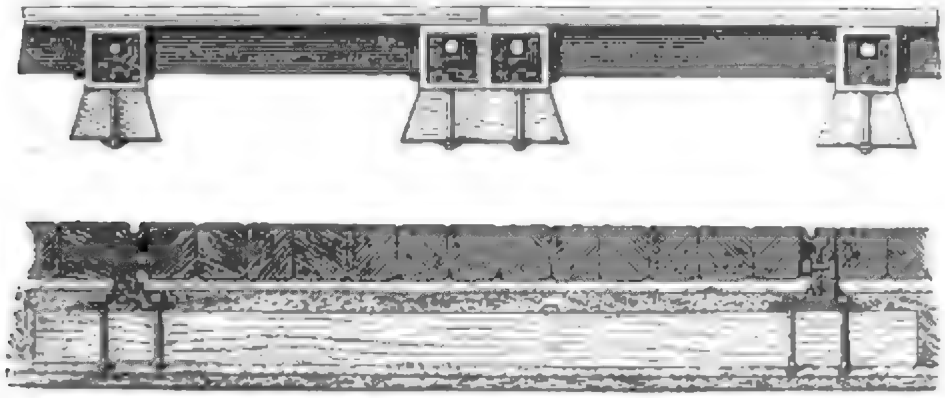
QUANTITIES PER MILE, SINGLE LINE, OF THE CITY OF OXFORD AND DISTRICT TRAMWAYS, 1881.

Excavation	1,175 cubic yards.
Concrete	587 ,,
Rails, 67 lbs. per yard	105 tons 6 cwt.
Joint chairs, 22¾ lbs. each . .	6 tons.
Fish-plates, 1¾ lbs. each . . .	9 cwt.
Gauge ties, 9 lbs. each	24 ,,
Bolts and nuts, ½ lb. each . .	8 ,,
Total weight of metal .	113 tons 7 cwt.

CHAPTER XXII.

VIGNOLES' SYSTEM.—NORTH LONDON SUBURBAN TRAMWAYS.—NORTH STAFFORDSHIRE TRAMWAYS.

Mr. Henry Vignoles' system was laid for the North London Suburban Tramways, Tottenham; and for the North Staffordshire Tramways, Stoke-upon-Trent, to a gauge of 4 feet 8½ inches, as illustrated by Figs. 107 and 108. The rail and chair are shown in section, Fig. 109. The rails are of steel, made with a central web, weighing 42½ lbs. per yard. The whole depth of the rail is 5 inches. The web is ⅜ inch thick at the lower edge. The chairs are placed on cross-sleepers at 2 feet 6 inches apart between centres. The joint chairs weigh 23 lbs. each; they give



Figs. 107 and 108. Vignoles' Way, Tottenham and Stoke. Scale $\frac{1}{24}$.

a bearing 10 inches in depth, and are fastened with four ¾-inch bolts and nuts to the sleepers, and two bolts and nuts to the rails. The intermediate chairs weigh 12 lbs. each; they give a bearing 5 inches in length, and are each fastened with two bolts and nuts to the sleepers, and one bolt and nut to the rails. A bearing plate is inserted between the rail and each chair, the upper part of which is curved to fit under the head of the rail, and the lower part is formed with a fillet, which fits under the web of the rail. The function of this plate is not obvious, except at the joints of the rails, where it acts as a fish. The sleepers are 6 feet long, 4 inches deep, 12 inches wide at the joints, and 7 inches intermediately. They are bevelled inwards from the lower side. The depth excavated is 12½ inches for the whole width. A 1-inch layer of fine gravel concrete is laid on the floor of the trench; then a 1-inch layer of sand, on which the sleepers are bedded. Around and above the sleepers hydraulic concrete is deposited for a depth of 5½ inches, topped with a 1-inch layer of sand and cement, on which a paving of 4-inch cubes is laid.

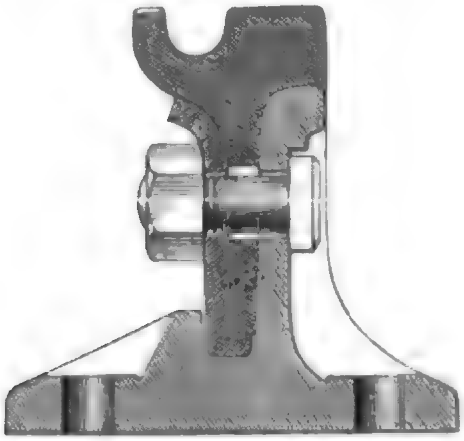


FIG. 109. Vignoles' Way, Tottenham and Stoke.—Rail. Scale ¼.

Mr. Vignoles gives the following estimated cost per mile, single line:—

QUANTITIES AND COSTS OF VIGNOLES' WAY, PER MILE, SINGLE LINE, 1881.

		£	s.	d.
Steel rails, 42½ lbs. per yard, 70 tons . .	@ £9	630	0	0
Wrought-iron fish-plates, 6 lbs. and 3 lbs. each, 6 tons	,, £7	42	0	0
Cast-iron chairs, 23 lbs. and 12 lbs. each, 23 tons	,, £5	115	0	0
Bolts, nuts, and washers, 5½ lbs., and 2¾ lbs. for each chair, 5 tons	,, £20	100	0	0
Joint sleepers, 250	,, 4s.	50	0	0
Intermediate sleepers, 1750	,, 3s.	262	10	0
Excavation, 1,760 lineal yards	,, 2s.	176	0	0
Hydraulic concrete, 900 cubic yards . . .	,, 8s.	360	0	0
Laying the way, 1,760 lineal yards . . .	,, 1s.	88	0	0
Total for the way, single line . .		1,823	10	0
Paving, 4-inch granite cubes, 4,550 square yards	,, 10s.	2,275	0	0
Total for the way and paving . .		£4,098	10	0

CHAPTER XXIII.

TRUSWELL'S SYSTEM.—DEWSBURY, BATLEY, AND BIRSTAL TRAMWAY—BIRSTAL AND GOMERSAL EXTENSION.

THE system of way, Mr. Kincaid's earliest form, laid for the original line of the Dewsbury, Batley, and Birstal Tramway, has been described. The rails were fixed to the chairs with vertical spikes driven into oak plugs—a mode of fastening which was insufficient for permanently retaining the rails under the action of the engines which were there at work. Mr. George Truswell designed a system of way having a reversible steel rail, Fig. 110, on cross-sleepers, for the Birstal and Gomersal Extension, 1·13 miles in length. The rail, Fig. 111, weighed 55 lbs. per yard, and was rolled in lengths of 24 feet. It was laid and keyed with oak keys in cast-iron chairs, placed 3 feet apart between centres, of which the joint-chairs are 6½ inches long at the seat of the rail, and weigh 37 lbs. each; and the intermediate

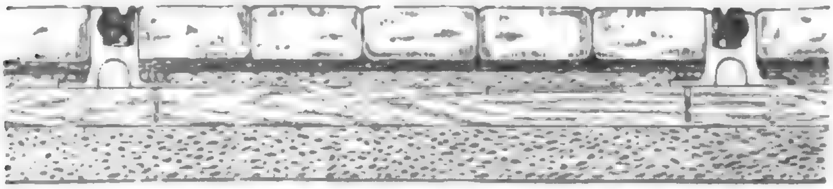


FIG. 110. Truswell's Way, Birstal. Scale $\frac{1}{24}$.

chairs are 3½ inches long, and weigh 25 lbs. each. The chairs are laid on sleepers of Baltic timber, 7 feet in length, 12 inches wide by 4 inches deep at the joints, and 8 inches wide intermediately. The chairs are each fixed to the sleepers by two oak trenails, and two coach-screws. The ground was excavated to a depth of 16 inches, for a width of 8 feet, for a single line. A layer of concrete, 5 inches deep, was deposited on the floor of the excavated space, on which the sleepers were laid, and the space was filled up about the sleepers to a total height of 10 inches, or 1 inch above the level of the sleepers. The concrete was made of 2 parts of broken stone to a 1½-inch ring gauge, 1 part of sand or fine screened ashes, and 1 part of blue lias lime. The rails are 3⅝ inches high, and 2¾ inches wide, comprising a tread 1⅜ inches wide, a 1-inch groove, and a guard flange ⅜ inch thick. They are hollowed sufficiently at one side to receive an oak wedge fastening. They stand 2⅝ inches clear above the concrete, and at the surface 6 inches above it, making room for 5-inch set paving, and 1 inch of fine screened ashes for bedding. The paving sets, 5 inches deep, are of Clee Hill granite, covering 4¼ square yards per ton of sets. The interstices are filled with melted pitch and tar in mixture.

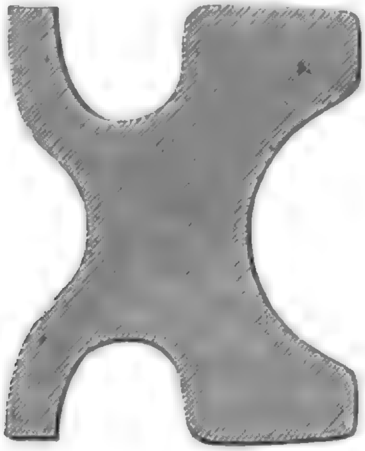


FIG. 111. Truswell's Rail, Birstal. Scale ½.

QUANTITIES AND COSTS OF ONE MILE, SINGLE LINE, OF TRUSWELL'S SYSTEM, OF THE DEWSBURY, BATLEY, AND BIRSTAL TRAMWAY, GOMERSAL EXTENSION, 1881.

		£	s.	d.	£	s.	d.
Steel rails, 55 lbs. per yard, 86 tons	@	11	15	0	1,010	10	0
Sleepers, 12 × 4 ins., by 7 feet, 220	,,	0	3	6	38	10	0
Do., 8 × 4 ins., by 7 feet, 1,540	,,	0	2	4	179	13	0
Joint chairs with fastenings, 440		0	2	2	47	13	4
Intermediate chairs with fastenings, 3,080	,,	0	1	10	282	6	0
Oak keys, 3,520, per 1,000	,,	2	10	0	8	16	0
Excavation, 2,086 cubic yards	,,	0	1	5	147	15	0
Concrete, 1,268 cubic yards	,,	0	8	0	507	4	0
Laying the way, 1,760 lineal yards	,,	0	0	10	73	6	8
Watching, lighting, and maintaining the way for six months					75	0	0
Total for the way					2,370	14	0
Granite paving complete, 4,400 square yards	,,	0	8	6	1,870	0	0
Total for the way and paving					£4,240	14	0

NOTE.—There are 46½ chairs per mile, single line; 22 cwts. of coach screws per mile; 7,040 oak trenails; and 7,040 coach screws per mile.

The way remains the same as when laid. The rails have not yet (1892) been reversed.

CHAPTER XXIV.

KERR'S SYSTEMS.

FIRST SYSTEM: IPSWICH TRAMWAYS, 1880.

MR. JOHN KERR'S first system, Fig. 112, consists of a solid girder rail laid upon wrought-iron sleepers of the section of an inverted trough, bedded in concrete. In the Ipswich tramways the way is laid to a gauge of 3 feet 6 inches. The sleepers are laid longitudinally, as in Figs. 112 and 113.

The rails, of Bessemer steel, weigh 58 lbs. per yard, and are rolled in lengths of 24 feet. They are of girder form, 3 inches in width at the head, as well as at the flange base. The tread of the rail is 1⅜ inches wide, the groove is 1 inch wide and $\frac{13}{16}$ inch deep, and the guard flange is ⅝ inch wide at the surface. The web is ⅝ inch thick near the head, and $\frac{7}{16}$ inch near the base. The base is ¼ inch thick near the edges, and is thickened up to ½ inch near the web.

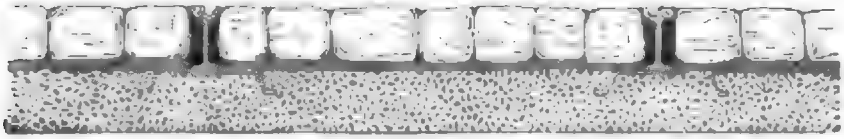


FIG. 112. Kerr's Way, Ipswich, Woolwich. Scale $\frac{1}{24}$.

The test applied to the rails was such that they were to submit, without rupture, to a deflection at the rate of 3 inches in a length of 5 feet. The deflection was to be produced by one blow of a tup, falling from a height of 10 feet, at least, on the middle of the rail, supported on bearings 3 feet apart. The rails were fished with wrought-iron plates 16 inches long, and four ¾-inch bolts and nuts. The holes in the plates are ¾ inch square; the bolts have round heads and square necks.

The sleepers are of ¼-inch wrought-iron plates, moulded as an inverted trough with inclined sides, 2¼ inches in total height, and 11⅞ inches in total width. The sleepers break joint with the rails. The rails are fastened to the sleepers by wrought-iron clips riveted to these. The weight of the sleepers, with clips, was 36½ lbs. per yard.

The ground was excavated for the whole width of the way, including paving, to a depth of 9½ inches below the surface; and a bed of concrete 4 inches deep was laid for the whole width. The hollows of the sleepers are thoroughly packed with concrete, the upper surface of the sleepers being flush with the concrete. The concrete is composed of 1 part of blue lias lime, 1 part of clean, sharp sand, and 4 parts of ¾-inch broken stone or of clean gravel. On a ½-inch bed of sand the paving sets, of granite, 5 inches deep, are bedded and rammed home level with the rails, between the rails, and for a width of 18 inches outside the line at each side. The stones are laid dry with interspaces of ½ to ¾ inch wide, and well packed with clean pebbles, from ⅛ to ⅜ inch in diameter, and grouted flush with Portland cement. The paving is covered with

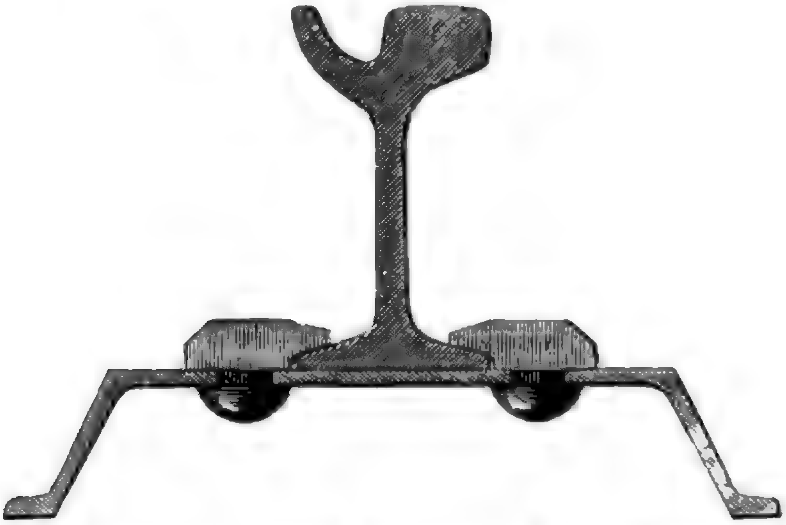


FIG. 113. Kerr's Wa Ipswich, Woolwich.—Rail and Sleeper. Scale ¼.

a layer of sharp, clean sand. The spaces at the side of the rails are likewise filled with pebbles and grouting.

Subjoined are particulars of the quantities per mile (single line, Ipswich Tramway, 3½ feet gauge, 1880) :—

Bessemer steel rails, 58 lbs. per yard	91	tons.
Wrought-iron sleepers and clips, 36½ lbs. per yard . .	57	,,
Wrought-iron fish-plates	2½	,,
,, ,, bolts and nuts	½	,,
	151	,,

Excavation, 1,045 cubic yards.
Concrete 440 ,,
Granite paving, 3,670 square yards.

WOOLWICH AND PLUMSTEAD TRAMWAY, 1881.

The materials and construction of the Woolwich and Plumstead Tramway, 3½ feet gauge, under the direction of the engineer, Mr. Thomas Floyd, are the same as those of the Ipswich Tramway, with the exception that in the former bituminous grouting was employed, and Portland cement concrete, 6 inches deep, was laid.

The following particulars show the quantities and costs per mile (single line, Woolwich and Plumstead Tramway, 3½ feet gauge, 1881) :—

	£	s.	d.	£	s.	d.
Way (as in the Ipswich Tramways), 151 tons, 1,760 lineal yards . . .	@ 0	15	4	1,349	6	8
Excavation, 1,270 cubic yards . . .	,, 0	3	0	190	10	0
Portland cement concrete, 600 cubic yards	,, 0	15	0	495	0	0
Cost of way				2,034	16	8
Paving, 3,670 square yards, granite sets	,, 0	10	0	1,835	0	0
Bituminous grouting, 3,670 square yards	,, 0	2	3	412	17	6
Cost of paving				2,247	17	6
Cost of way and paving				£4,282	14	2

KERR'S SECOND SYSTEM.—ALFORD AND SUTTON STEAM TRAMWAYS.

In this tramway, (Fig. 116), girder rails, 4½ inches high, weighing 45 lbs. per yard, are laid to 2½ feet gauge, on transverse concrete sleepers 3 feet apart between centres. Steel tie-plates, ¼ inch thick, are laid on and imbedded in the sleepers. The road is macadam. There is no paving, except at passing places, where 4-inch cubes were laid.

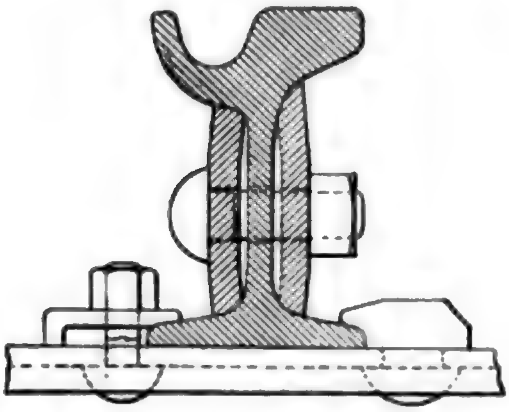


FIG. 114. Alford and Sutton Steam Tramways: Section of Rail, Sleeper, and Fastening. Scale ¼.

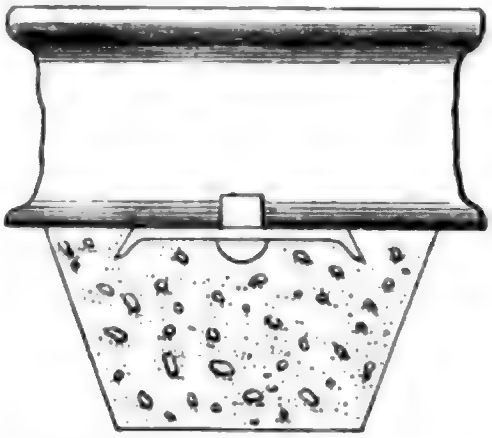


FIG. 115. Alford and Sutton Steam Tramways: Sleeper and Fastening. Scale about ⅛.

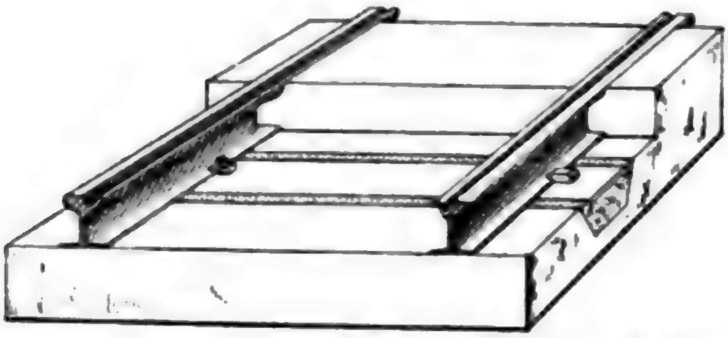


FIG. 116. Alford and Sutton Steam Tramways: Cross Section. Scale 1/32.

This line is now closed. It was worked with steam locomotives weighing 11½ tons, when, it is stated, it bore the weight of the traffic perfectly.

KERR'S THIRD SYSTEM.—BUCHAREST TRAMWAY; MADRID TRAMWAY.

This way (Fig. 117) is laid with girder rails, 5 inches high, weighing 60 lbs. per yard. The rails are laid on timber sleepers, 8 inches by 4 inches deep, placed 9 feet apart, in a macadam road.

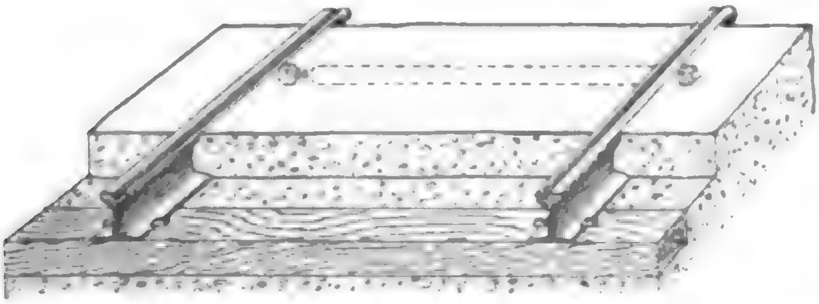


FIG. 117. Bucharest Tramways; Madrid Tramways: Cross Section.

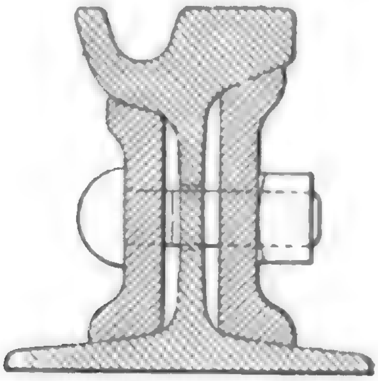


FIG. 118. Bucharest Tramways; Madrid Tramways: Section of Rail and Fastenings. Scale ¼.

CHAPTER XXV.

SPECIAL TRAMWAYS.

GLASGOW HARBOUR TRAMWAY.

TRAMWAYS suitable for goods-yard traffic, consisting of two cast-iron tram-plates and iron paving between them, have been down in the Devonshire Street Station of the Great Eastern Railway, London, for upwards of 30 years.

A cast-iron tramway, bedded in concrete, chiefly designed for street or dock-lorrie traffic, was patented in December, 1869, by Messrs. Ransome, Deas, & Rapier. A tramway on this system, 4½ miles long, was laid, in 1870, on the Broomielaw Quay, at Glasgow. It is adapted for both flanged and unflanged vehicles. The way consists of hollow rectangular blocks of cast iron, Figs. 119 and 120, 5 feet long, 10 inches wide, and 8¼ inches deep; 1 inch thick at the top, ½ inch at the sides. A groove, 1½ inches wide, and 1¼ inches deep, is formed in the middle of the upper surface of

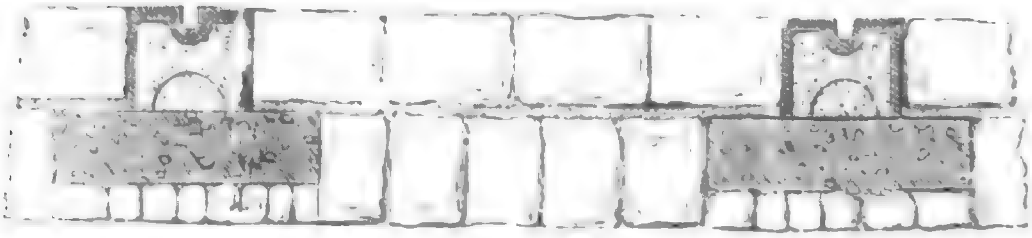


FIG. 119. Glasgow Harbour Tramway:—System of Messrs. Ransome, Deas, & Rapier. Scale $\frac{1}{24}$.

the block, for wheel-flanges. The upper surface, cast on a chill, is formed with grooves on each side, to afford a foothold for horses. Recesses at the ends are cast to receive fish-plates, which are bolted in the ordinary manner. The blocks are entirely filled with concrete, composed of 7 parts of gravel and sand, and 1 part of Portland cement, well punned, and allowed to lie three or four days to set. The bottom was prepared like that of an ordinary first-class street or dock-road, consisting of dry rubble, and two lines of concrete were prepared for the tram-blocks, 1 foot 10 inches wide, and 6 inches deep. The tramway blocks were then turned over, and were fixed with cement to the bases of concrete.

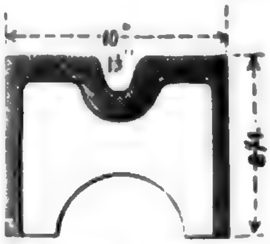


FIG. 120. System of Messrs. Ransome, Deas, & Rapier. Section of rail, 203 lbs. per yard. Scale $\frac{1}{12}$.

At first, it seemed desirable to have bottom flanges at the outsides of the blocks, but it was found inconvenient for laying the paving sets. Bottom flanges were then applied to the insides; they answered well, but for the sake of economy of material, flanges were entirely dispensed with, and the tramway blocks constructed as shown in the illustrations have been found to be perfectly steady. The road was made thoroughly rigid; and the blocks, once laid, remained there. At first, cross tie-bars were used, but it was found that they were not necessary, for the blocks could not be got to stir even when it was required to move them. In a few instances, where it was necessary to have the blocks raised for laying water-pipes or gas-pipes, it was found that they had stuck to the concrete beneath, and had to be actually cut away.

The quantities and costs for this system of tramway are as follows, for a single way:—

SINGLE LINE.

Cast-iron blocks, 406 lbs. per lineal yard of 2 rails; or 319 tons per mile.

Concrete, 0·30 cubic yard per lineal yard; or 528 cubic yards per mile.

	Per lineal yard.			Per mile.		
	£	s.	d.	£	s.	d.
Cost of cast-iron blocks, including fish-plates, and bolts and nuts	1	5	0	2,200	0	0
Cost of concrete, @ 15s 6d. per cubic yard	0	4	8	410	13	0
Laying	0	2	6	220	0	0
	£1	12	2	£2,830	13	0

To this is to be added the cost for excavation and for pavement.

The experience of this tramway at Glasgow has been very satisfactory. From 100 to 140 railway waggons pass over the busiest part of the tramway daily. Contractors' locomotives also constantly pass, frequently dragging heavy loads upon bogies to the 60-ton crane. The highest speed of the railway vehicles is about 5 miles per hour, and of the street lorries 6 miles per hour. It is notable that, when horses have to turn off the tramway, they return to it of their own accord. From the report of Mr. Deas, the engineer of the Clyde Navigation, it appears that none of the cast-iron blocks have been broken, and that the chilled surfaces are now in as good condition as when the way was first laid. It was originally expected that, in order to get the blocks to lie steady, they would require to be cast in 10-feet lengths; but it was found not to be necessary, for the 5-feet blocks never showed any signs of movement.

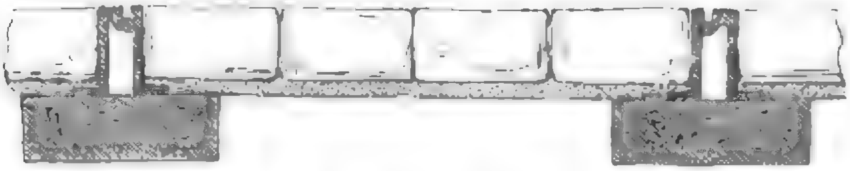


FIG. 121. System of Messrs. Ransome, Deas, & Rapier, for lighter traffic. Scale $\frac{1}{24}$.

A variety of the same kind of tramways is shown on Fig. 121, for flanged vehicles only. The cast-iron block is only 4 inches wide at the surface, and it is formed with side flanges at the bottom, making up the base to a width of 9 inches. The edges are notched at intervals of 3 inches or 4 inches for the use of vehicles crossing the road. The blocks are filled with concrete, and laid with cement on two lines of concrete, 6 inches deep and 18 inches wide. The quantities and costs for a single way are as follows :—

SINGLE LINE.

Cast-iron blocks, 308 lbs. per lineal yard of two rails ; or 242 tons per mile.

Concrete, ⅕ cubic yard per lineal yard ; or 352 cubic yards per mile.

	Per lineal yard. £	s.	d.	Per mile. £
Cost of cast-iron blocks, including fish-plates, bolts, and nuts	0	19	0	1,672
Cost of concrete, @ 16s. 3d. per cubic yard . .	0	3	3	286
Laying	0	2	3	198
	£1	4	6	£2,156

In 1871, a length of about 700 yards of tramway on this system was laid in the gas-yard of the Glasgow Corporation. The manager reported that it worked very well, had not required any repair, and had not occasioned any trouble.

The tramways, as above constructed with cast-iron blocks, served the original purpose very well. But when heavy locomotives were permitted to run on them they gradually went to pieces and were superseded by a new tramway of steel, suited for the heavy traffic that was imposed on it. A steel rail tramway

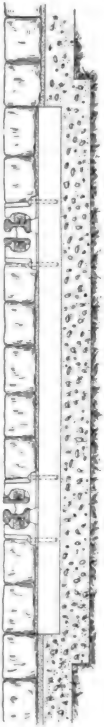
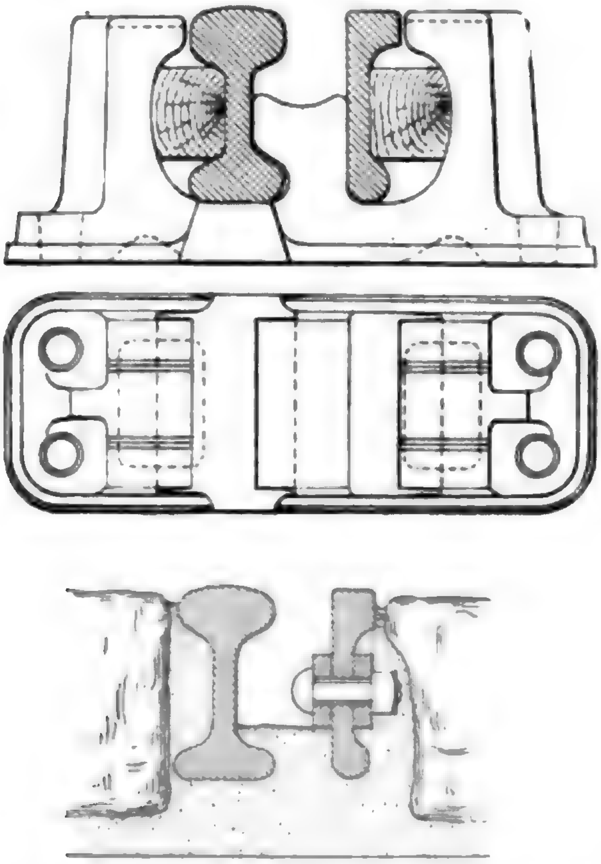


FIG. 122. Clyde Navigation, Glasgow Harbour Tramways: Cross Section of Way. Scale $\frac{1}{24}$.

was designed for the purpose in 1887 by Mr. Deas' son, as shown in Figs. 122 and 123. The way consists of a heavy double-headed steel rail with a steel guard-rail, carried in chairs on creosoted cross sleepers, 2 feet 9 inches apart between centres. The tops of the chairs are laid flush with the pavement, and thereby prevent much of the wear that would otherwise take place alongside the rail.

Estimates of costs per mile of single line are here subjoined.



Figs. 123. Clyde Navigation, Glasgow Harbour Tramways : Chair. Scale ¼.

The first estimate applies to a line constructed on the new roadway, including cost of excavation, concrete bottoming, and paving; whilst the second estimate is for a line laid down on an existing roadway. The sleepers are 10 inches wide, 5 inches deep, 8 feet 11 inches long, creosoted. The chairs are of cast iron, spiked to sleepers. The rails are of steel, single headed, weighing 80 lbs. per lineal yard, in lengths of 32 feet. They are fished with steel plates, 18 inches long. The guard rails are formed with bulbs, and are of steel, weighing 39·90 lbs. per lineal yard. The ground is excavated to a depth of 17½ inches for a width of 8 feet 11 inches, for a single line. Concrete is made with Portland cement 6 inches thick. The paving or causeway is of granite 6 inches deep.

CLYDE NAVIGATION.

GLASGOW HARBOUR TRAMWAYS.

ESTIMATED COST PER MILE FOR SINGLE LINE.

I.—*For Tramway on a New Roadway.*

		£	s.	d.	£	s.	d.
1. Rectangular sleepers of Baltic, Riga, or Windau red-wood, 8 feet 11 inches × 10 inches × 5 inches, creosoted with 2½ gallons per sleeper, placed about 2 feet 9 inches centres, No. 1,980	@	0	3	6	346	10	0
2. Cast-iron chairs, 58 lbs. each, No. 3,960, 102 tons 10 cwt. 2 qrs. 24 lbs.	,,	4	0	0	410	2	10
3. Wrought-iron spikes 5⅞ inches long × ⅞ inch diameter, fixing chairs to sleepers, two to each chair, weighing 19¼ oz. each, No. 7,920, 4 tons 5 cwts. 0 qrs. 8 lbs.	,,	7	11	8	32	5	2
4. Single-headed steel rails, 80 lbs. per lineal yard, in lengths of 32 feet, 125 tons 14 cwts. 1 qr. 4 lbs.	,,	5	19	6	751	2	10
5. Steel fish-plates for 80 lb. rails, 18 ins. long, 22 lbs. per pair, 330 pairs, 3 tons 4 cwts. 3 qrs. 8 lbs.	,,	6	0	0	19	8	11
6. Wrought-iron bolts and nuts for fish-plates, 4 ins. long × ⅞ in. diameter, four to each pair of fish-plates, 5·20 lbs. per set of four, 15 cwts. 1 qr. 8 lbs.	,,	9	0	0	6	17	11
7. Steel bulb rails 39·90 lbs. lineal yard, in lengths of 32 feet, 62 tons 14 cwts.	,,	10	10	0	658	7	0
8. Steel fish-plates for bulb-rails, 18 ins. long, 8¾ lbs. per pair, 1 ton 5 cwt. 3 qrs. 4 lbs.	,,	12	0	0	15	9	5

CLYDE NAVIGATION (*continued*).

		£	s.	d.	£	s.	d.
9. Wrought-iron bolts and nuts for bulb-rail fish-plates, 2½ ins. long × ⅝ in. diameter, 4 to each pair, 2·20 lbs. per set of four, 6 cwts. 2 qrs.	@	12	0	0	3	18	0
10. Oak keys, 5 ins. × 2 ins. × 2¼ ins., No. 7,920, per 1,000	,,	2	5	0	17	16	5
11. Cartage of rails, 188 tons 8 cwt. 1 qr. 4 lbs.	,,	0	1	6	14	2	7
12. Labour laying sleepers, chairs, and rails, lineal yards 1,760	,,	0	1	0	88	0	0
(£1 6s. 10d. per lineal yard for materials and laying.)							
Excavation, including carting away, 5,280 ft. × 8 ft. 11 ins. × 17½ ins., cubic yards 2,543	,,	0	1	0	127	3	0
Portland cement concrete, 9 to 1, 6 ins. thick, 5,280 feet × 8 ft. 11 ins. × 6 ins. cubic yards, 872	,,	0	10	0	436	0	0
Granite causeway 6 ins. deep, including bed of sand and grouting joints of stones with bitumen, 5,280 × 8 ft. 11 ins. less 4 rails (5⅜ + 5⅜ = 10¾); square yards, 4,705·05	,,	0	9	0	2,117	9	6
Concrete bottoming between sleepers. 5,280 ins. less sleepers 1,980 @ 10 ins. wide 1,650 —— 3,630 ins. × 8 ft. 11 ins. × 4½ ins.; cubic yards, 449·54	,,	0	10	0	224	15	4
Cost per lineal yard		1	13	0	2,905	7	10
Total cost per lineal yard		2	19	10	£5,269	8	11

II.—*For Tramway on an Existing Roadway.*

	£	s.	d.	£	s.	d.
Tramway materials and laying				2,364	1	1
Cost per lineal yard	1	6	10			

CLYDE NAVIGATION (*continued*).

		£	s.	d.	£	s.	d.
Lifting and relaying granite causeway, 6 ins. deep, and grouting with bitumen, 5,280 ft. × 8 ft. 11 ins. less 4 rails, 10¾ ins. 0 10¾ 8 0¼ square yards 4,705·5	@	0	2	10	666	12	3
Preparing bottoming, 5,280 ft. × 8 ft. 11 ins.; square yards 5,231⅑ . . .	,,	0	0	6	130	15	6
Concrete bottoming between sleepers, 5,280, less sleepers 1,980 @ 10 ins. wide. 1,650 3,630 ft. × 8 ft. 11 ins. × 4½ ins.; cubic yards, 449·54	,,	0	10	0	224	15	4
Cost per lineal yard		0	11	7	1,022	3	1
Total cost per lineal yard . . .		1	18	5	£3,386	4	2

BELFAST HARBOUR TRAMWAY.

A single line of tramway, specially designed for the traffic, was laid, in 1869, on the quays at Belfast Harbour, under the superintendence of Mr. Lizars, the engineer to the Harbour Commissioners. It was opened in January, 1870. It was a single line, with sidings. It consisted of two longitudinal sleepers of pitch pine, or of Memel timber, 9½ inches wide and 7 inches deep, Fig. 124, upon which an ordinary iron bridge rail, 4 inches deep, and weighing 80 lbs. per yard, was laid and fastened with spikes through the flanges. A check-rail of L section, also 4 inches deep, weighing 39 lbs. per yard, was laid and spiked alongside the bearing rail, upon the same sleeper, leaving an interval or groove of a width of 1⅜ inches. The ground was excavated with trenches for the sleepers, which were bedded upon gravel or on ashes. The pavement consisted of oblong sets, 7 inches deep, on a bed of sand grouted with lime, abutting on the sleepers.

It is apparent that, on this system, wide vacancies were created between the rails and the pavement, 2¼ inches at each side; these vacancies were filled with concrete flush with the pavement. But there was a want of stability in the combination. It was very liable to get out of order; the check rail, no matter how tightly spiked to the sleepers, being easily pressed and moved inwards against the non-resistant concrete; and the groove was thus widened to an extent which made it dangerous for traffic.

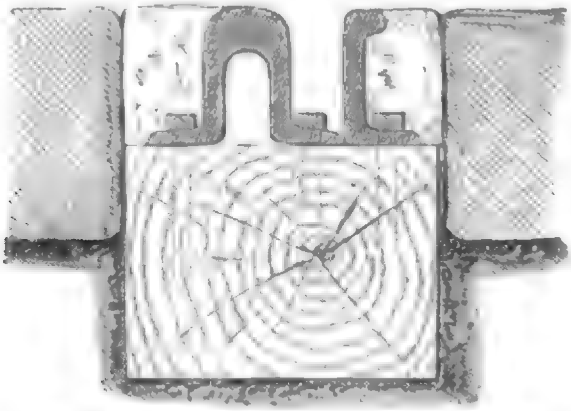


FIG. 124. Belfast Harbour Tramway:—Lizar's System. Scale ⅙.

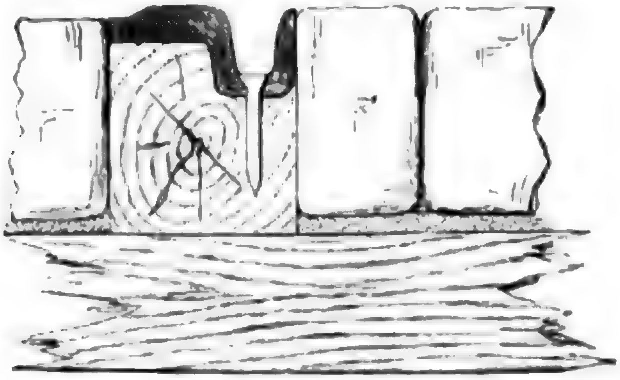


FIG. 125. Belfast Harbour Tramway:—Salmond's System. Rail, 70 lbs. per yard. Scale ⅛.

A better system was subsequently designed and employed by Mr. T. R. Salmond, the present engineer to the Commissioners, for extension and for replacements of portions of the line. A single iron rail, Fig. 125, weighing 70 lbs. per yard, was substituted for the combined bridge rail and check-rail. It is 6 inches wide, formed with a groove 1¼ inches wide and 1¾ inches deep, and a raised bearing surface at one side of the groove. The average thickness is about ¾ inch. It is fastened by ⅜-inch vertical spikes, ragged, with countersunk heads, to a longitudinal sleeper, 6 inches square, at intervals of 3 feet, except at the joints, where it is fastened by ⅝-inch bolts and nuts. The nuts, at the under side, are screwed up on a fish-plate of iron of the width of the sleeper, 12 inches in length and ½ inch thick. The longitudinal sleepers are laid on and spiked to cross-sleepers of larch, 9 feet in length, laid at distances of 4 feet between centres.

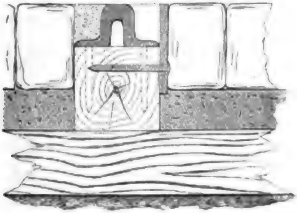


FIG. 126. Belfast Harbour Tramway:—System adopted for sharp curves. Scale, ⅛.

The pavement consists of sets, 6 inches deep, 3½ to 4 inches wide, and from 8 to 12 inches long, laid close to the sleeper and rail at each side.

In the construction of sharp curves, the combination, Fig. 126, is applied, consisting of a bridge-rail, laid on a longitudinal sleeper, 6 inches square, and a flat plate, ¾ inch thick, 6½ inches deep, spiked to one side of the sleeper, forming a 1¾-inch groove. The rail of the section here shown lends itself to the formation of curves more readily than the solid wide rail used for the straight portion of the line. It may be noted, too, that the lateral slab which is placed as a check-rail may be more firmly fixed to the sleeper than the check rail used in the earlier design.

The new rails were ordered in 1873, with a flat surface, and were partially used for constructing 100 yards of way, in 1875, of which 50 yards was laid in replacement of a portion of the old line. The remainder was used for traversing steam cranes along the quays. In 1875 new rails were ordered, having a raised surface; they were laid on the new Queen's Quay. The new lines gave great satisfaction; it was reported that they laid solidly, and the fastenings kept tight under the traffic of the railway wagons and locomotives by which they were traversed. The permanency of the fastenings, it is clear, was due to the disposition by which they were placed entirely out of the range of the wheels.

The prices paid for the materials of the new way were as follows:—

	£	s.	d.	
Rails, 70 lbs. per yard, delivered . .	7	10	0	per ton.
Longitudinal sleepers, 6 inches square, cut from log, including the labour of laying	0	3	0	per cubic foot.
Larch cross-sleepers, 9 ft. long .	0	3	0	each.
Square setting	0	8	0	per square yard.
Switches and crossings	13	0	0	per set.

GUINNESS'S BREWERY TRAMWAYS, DUBLIN.

The transport of goods and materials in Guinness's Brewery is effected by means of a double system of tramways: a tramway of

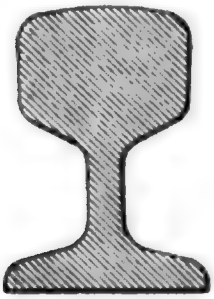


FIG. 127. Guinness's Brewery Tramways: Section of Rail. Scale ⅓.

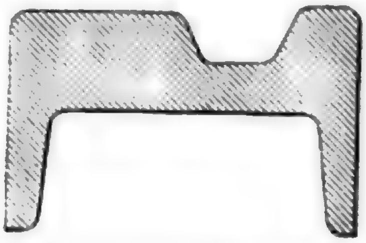


FIG. 128. Guinness's Brewery Tramways: Section of Rail. Scale ⅓.

5 feet 3 inch gauge—the standard Irish gauge—and a tramway of 22 inch gauge, for the work of transport within the brewery, and for communication between the higher and lower premises. For the narrow-gauge lines the first rails were of iron, weighing 16 lbs. per yard. The weight has been increased to 46 lbs. per yard in the present steel rails, shown in Fig. 127. The tram rail, Fig. 128, forms by far the greater part of the system; it is of iron, weighing 56 lbs. per yard, and, as in Fig. 129, is fastened to rebated longitudinal timbers, which are laid on cross-sleepers. In some cases they are laid directly upon concrete, and wrought-iron cross-ties are used. The most recently-constructed portion was laid with steel girder rails, weighing 76 lbs. per yard, as in Fig. 130, laid on cross-sleepers. The foot of the rail is made narrow, in order to allow of its being easily bent to small radii. As there is horse traffic over the broad-gauge rails, these are grooved as in Fig. 131, and the wagons run on the wheel flanges, in the grooves, thus keeping the tread of the wheel well clear of the pavement, and avoiding the use of a guard rail. The total length of the line and sidings is about 5½ miles.

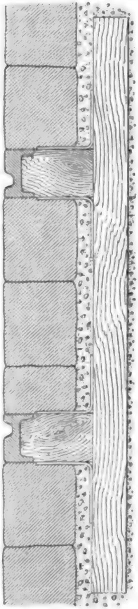


FIG. 129. Guinness's Brewery Tramways: Scale $\frac{1}{16}$.

For switches, the tongued point, as used on tramways, has been adopted for tram-lines, and the crossings, when very close to one another, are made of cast-steel rails, bolted upon a cast-iron plate, with a wood liner between.

The cost of laying the narrow-gauge line, of 22-inch gauge, amounted to £4,070 per mile, or £2 6s. 3d. per lineal yard. For this sum is included the tram rails fastened to rebated longitudinal sleepers, laid on cross-sleepers, bedded in concrete for the depth of the cross-sleepers, and ballasted up with gravel, paved with Welsh sets between the rails and for an outer width of 18 inches at each side; including all points, crossings, and curves, of which there are many. The rails were specified to be capable of being bent to a curve of 10 feet radius without fracture, the width of the rail being in the plane of curvature.

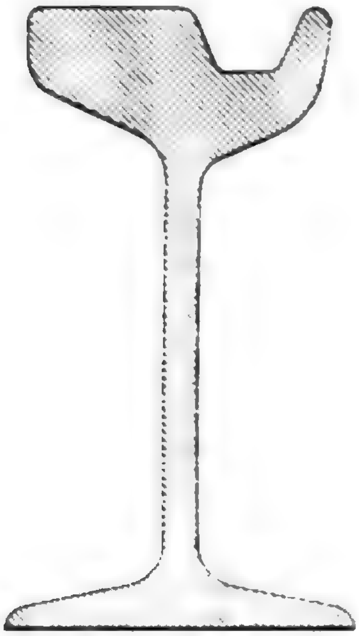


FIG. 130. Guinness's Brewery Tramways: Section of Rail, 22-inch gauge. Scale ½.

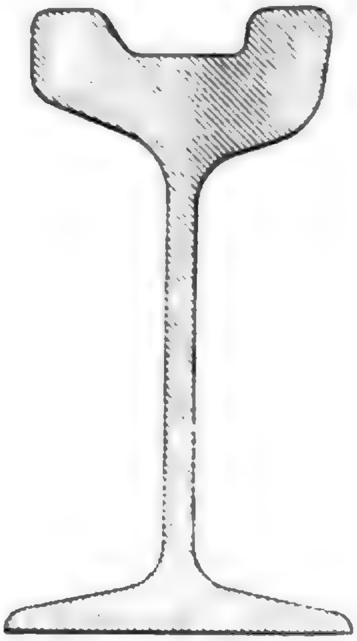
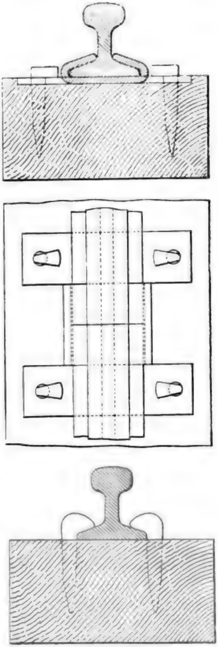


FIG. 131. Guinness's Brewery Tramways: Section of Rail, 5¼ feet gauge. Scale ½.

TRAMWAY IN HORWICH LOCOMOTIVE WORKS, LANCASHIRE AND YORKSHIRE RAILWAY.

Several miles of tramway have been designed and laid at Horwich locomotive works by Mr. John A. F. Aspinall, to a gauge of

18 inches, with foot-rails weighing 26 lbs. per yard, according to the section, Figs. 132, 133, and 134. The base of the rail is 2⅜ inches wide, and the rail stands 2½ inches high. The head is 1⅜ inches wide, the web is 7/16 inch thick, the rail is laid on longitudinal timber sleepers, 7 inches wide, 3½ inches deep. The rails are spiked to the sleepers as shown in Fig. 134, and they are fished at the joints by a slipper-plate formed out of a flat plate ¼ inch thick.



FIGS. 132, 133, 134. Tramway, Horwich Locomotive Works: Rail and Fastenings. Scale ¼.

EDGE'S WAY.

Mr. C. A. Edge patented, November 30, 1877, a system of tramway, Figs. 135 and 136, without grooves in the rails. The rails, hollow in section, are perforated at the surface with holes, either round or oval, at equal intervals, into which corresponding studs fastened to the wheels of the car enter in succession as the car advances. By this means the wheels are kept on the track, without the aid of flanges and grooves. The studs are applied only to the wheels at one side of the car. Any impediments lodged in the holes are crushed or are squeezed out by the action of the studs. An experimental piece of tramway of this kind, in the form of the figure 8, a quarter of a mile in length, was laid down at Birmingham, and was traversed by a car built for the purpose. The car, it is stated, travels at a speed of 12 miles per hour, without leaving the rails, whilst a passenger would be unable to detect any difference between the running of this car and that of an ordinary car with flanged wheels on grooved rails.

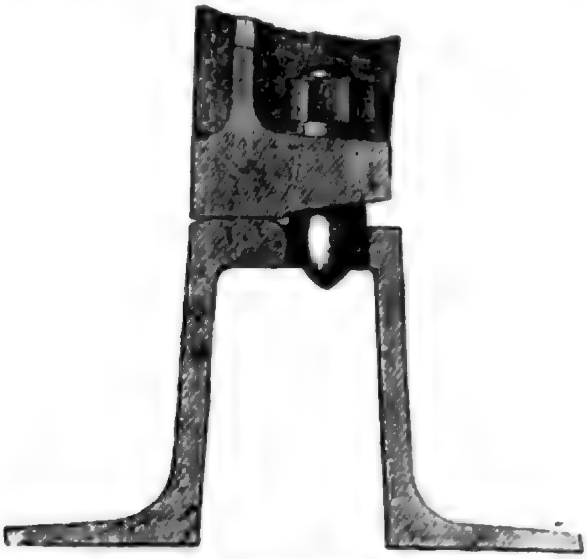


FIG. 135. Edge's Way. Section of Rail and Wheel. Scale ¼.

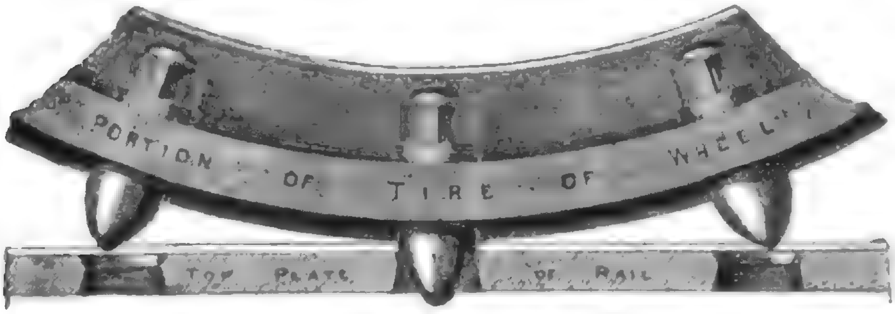


FIG. 136. Edge's Way. Side view of Wheel. Scale ¼.

The Edge system was laid, with cast-steel rails, 70 lbs. per yard, for a length of three miles in the City of Brunswick, in 1879—80, one-third of the length consisting of curves of from 40 to 110 feet radius. The first route, 1½ miles in length, was opened in October, 1879, and the remaining length of 1½ miles in 1880. It is reported that, in the month of December, 1879, when snow and frost prevailed, the system, it was found, could safely be used during weather which would have stopped running on other systems of tramway. The cars, it is said, run with as little resistance as those on ordinary ways. In March, 1881, it was reported that during the previous eighteen months, upwards of 50,000 journeys, amounting to about 100,000 miles run, were performed without any extraordinary wear of either the wheels or the rails. It is stated by the City Surveyor, that "the rails with holes have offered no interference whatever, either to heavy or to light vehicles, nor to foot traffic;" and it was remarked by a local newspaper that "the cars move along with the same quiet ease and smoothness as in the old system, and the friction is apparently less."

CHAPTER XXVI

SUPPLEMENTARY.—ON FOREIGN TRAMWAYS.

PARIS.

WHEN M. Loûbat returned to Paris from America, he introduced his system, slightly modified, Figs. 137 and 138, and, in 1853, laid a line of tramway in Paris, from the Place de la Concorde to Passy, in the Avenue de la Reine. This was the first horse tramway laid in France. It was laid to a gauge of 1·54 metres, or 5 feet ½ inch. The rail was of a semi-hexagonal section at the lower side, to rest upon a wood sleeper, which was chamfered to receive it, and upon which it was spiked diagonally through the sides. A fish-plate of iron, 6 inches long and ⅜ inch thick, was laid under each joint. The rail weighed 19 kilogrammes per metre, or 38 lbs. per yard. It was 3 inches wide at the surface; the groove was 1¼ inches

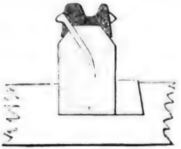


FIG. 137. Loûbat's Tramway:—Section of Rail and Sleeper. Scale ⅛.

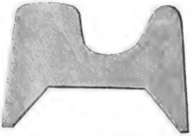


FIG. 138. Section of Loûbat's Rail, 38 lbs. per yard. Scale ½.

wide and ⅞ inch deep; whilst the tread was only 1⅛ inches wide. The longitudinal sleepers were 4 inches wide by 6 inches deep, and were laid upon transverse sleepers 6 inches wide and 4 inches deep, placed at 2 metres, or 6 feet 7 inches apart, between centres. The transverse sleepers were notched to receive the longitudinals, which were fixed into them by wood keys. The spikes proved to be insufficient as fasteners, for they were either broken or pulled out, probably for want of a good bearing on the sleeper, on which, it is manifest, the rail must have been displaced by the eccentric pressure of the load.

This rail was laid by the Compagnie Générale des Omnibus, on the lines from the Place de la Concorde to Sèvres and to Boulogne.

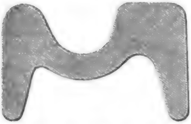


FIG. 139. Section of Rail, between Sèvres and Versailles, 32 lbs. per yard. Scale ½.

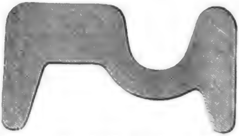


FIG. 140. Section of Rail, to replace Sections, Figs. 138 and 139:—46 lbs. per yard. Scale ½.

The next section employed, Fig. 139, was that of the tram rails laid by a private company between Sèvres and Versailles. The rail weighed 16 kilogrammes per metre, or 32 lbs. per yard; it was hollowed at the lower surface, for the sake of economy of material.

These rails, Figs. 137, 138, and 139, according to M. Goschler,* lasted ten years. At the end of this period the rolling surface had worn so much that the flanges of the car-wheels lodged on the bottom of the grooves. A rail, Fig. 140, of a heavier section, weighing

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* "Les Chemins de Fers Nécessaires," in the *Comptes Rendus de la Société des Ingénieurs Civils*, 1873.

46 lbs. per yard, calculated to last 20 years, was employed to replace the lighter rails. A similar rail, Fig. 141, was laid by the Omnibus Company on the route between the Arc de l'Étoile and the Trône, on the Tramways Nord. It was 4 inches wide, and 2·16 inches deep, and had a groove 1¼ inches wide. It was fixed on a longitudinal wood sleeper, like its predecessor, by vertical bolts, through the bottom of the groove, with countersunk heads and nuts. The rails were rolled in lengths of 6 metres, or nearly 20 feet, and they were fished at the joints with iron plates, formed to fit the lower surfaces of the rails.

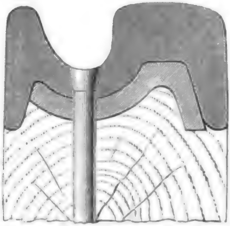

FIG. 141. Section of Rail and Fastening, Tramways Nord, 46 lbs. per yard. Scale ½.

It was early assumed that transverse sleepers were not necessary, and they were dispensed with as the lines came under repair. Cross tie-bars of wrought iron were employed instead of the sleepers, but even these were, after a time, abandoned. When the lines were laid in macadam, without any paving, the cost of maintenance was very great, due to the practice of the running of ordinary vehicles on the track of the tramway. A continual supply of new macadam was required for a width of 10 inches on each side of the rails, and, of course, the perpetual renewal of loose stone led to a greater increased resistance on, and wear of the tramway, occasioned by the detritus of the covering at the sides. To avoid such serious objections, the Omnibus Company replaced the macadam by paved margins next the rails in the outer portions of the system, and by a general paving on the lines within the city.

Though it appears that the first line of tramway laid, that of M. Lôubat, was laid to a gauge of 1·54 metres, or 5 feet ½ inch, the tramways subsequently constructed were laid to the railway gauge, 1·44 metres, or 4 feet 8½ inches; or to 1·43 metres, or 4 feet 8½ inches. Uniformity of gauge was adopted with a view to establishing communications between the railway goods-stations. The expectation was futile.

The schedule of prices, adopted in 1867, for laying the tramways in macadam roads, according to M. Goschler, was as follows:—

TRAMWAYS IN PARIS.—SCHEDULE OF PRICES, 1867.

		Francs.	£	s.	d.	
Rails, drilled with 10 countersunk holes, per 100 kilogrammes	@	26	10	8	0	per ton.
Bolts or fishes, per 100 pieces . .	,,	22	0	17	5	
Oak sleepers, longitudinal, 6 inches by 8 inches, per stère	,,	134	0	3	0	cubic ft.
Broken mill-stone (macadam) per cubic metre	,,	12	0	7	3	cubic yd.
Sand, per cubic metre	,,	3	0	1	10	,,
Labour, per hour	,,	0·35			3·32	per hour.
One-horse cart, per hour . . .	,,	1	0	0	9½	,,

On the basis of these prices, the cost per yard of the construction of a single line of tramway with the 46-lb. rails, Fig. 141, was as follows:—

COST PER YARD, SINGLE LINE.—RAILS 46 LBS. PER YARD.

	s.	d.
Rails	8	8
Longitudinal sleepers	2	10·8
Shaping the sleepers	0	8·7
Carried forward	12	3.5

COST PER YARD (*continued*).

	s.	d.
Brought forward	12	3·5
Bolts	0	7·7
Fishes	0	5·1
Washers	0	0·7
Excavation	0	6·6
Fitting together	0	1·7
Laying and packing	0	5·2
Land	0	1·7
Broken stone	0	8·7
Watering and rolling	0	2·2
Watching and general expenses	0	8·3
Total	16	4

or, £1,437 6s. 8d. per mile.

The rail adopted for the Tramways Nord, in the Avenue de la Grande Armée, is shown in Fig. 142.

The section of rail which was next laid by the Tramways Nord, in 1873, on the macadam road between the Porte Maillet and the Pont de Neuilly, is shown in Fig. 143, adopted from English practice. The weight of the rail is 60 lbs. per yard; it is bolted down through the grooves to longitudinal sleepers of oak, 4 inches wide and 6 inches deep, laid on transverse sleepers, 6 inches wide and 3⅛ inches deep, placed at distances of 5 feet apart between

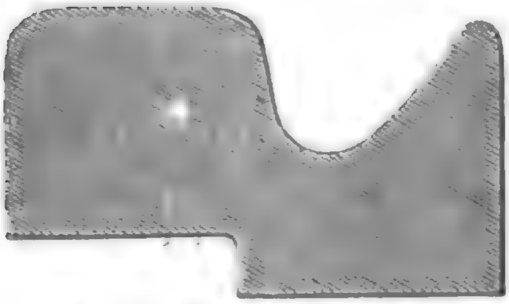
FIG. 142. Section of Rail in the Avenue de la Grande Armée. Scale ⅓.

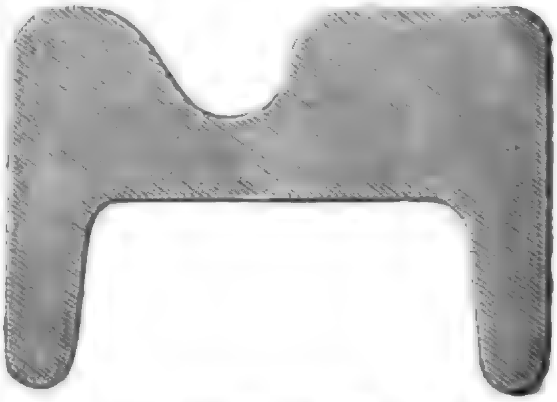
FIG. 143. Section of Rail, Avenue de Neuilly, 60 lbs. per yard. Scale ½.

centres. The cost of this way per mile of single line is estimated at £1,418, including the cost of rails, cast-iron joint chairs, and brackets, bolts, sleepers, laying the way, watching, and sundry expenses. Though the section of rail was copied from English practice, it appears that the valuable function of the flanges, in superseding with side fastenings the vertical holding bolts, was not apprehended.

The whole cost of construction of the Tramways Nord of Paris is given in an Addenda-Dunod, 1877, from which the following summary is deduced :—

TRAMWAYS NORD.—COST PER LINEAL YARD OF DOUBLE WAY ON A PAVED ROAD.

	£	s.	d.
Lifting pavement and excavation . .	0	2	2
Paving	1	7	7
Way	1	15	7
Total	£3	5	4

Or, £5,750 per mile.

From the balance-sheet of the company it appears that the total capital expenditure on these tramways amounted to £31,900 per mile.

Mr. Oppermann gives an analysis of the cost of working the line between St. Germain-des-Près and Montrouge, a part of the Tramways Sud, in Paris. The line is 3·12 miles in length. One car makes 20 trips in 16 hours per day, and runs (3·12 × 20 =) 62·40 miles per day. Each car contains 16 passengers inside, 18 on the roof, and 10 on the platforms; in all, 44. Each car is drawn by two horses, relieved four times, making 10 horses for each car.

	Francs.
One horse costs per day for fodder . .	4·50
Shoeing, stabling, attendance, renewal, &c.	1·00
Total for one horse	5·50
Horse labour per car per day (5·50 × 10) .	55·00
,, ,, per mile run ·88 franc, or 8·37 pence.	

The system of tramway adopted and put in execution by M. Francq, for the Versailles Tramways, in 1875, is illustrated by Figs. 144, 145, and 146, with rails on a timber substructure of longitudinal sleepers laid upon transverse sleepers. The rail weighs 30½ lbs. per yard, it is of a section comparatively shallow, 1⅜ inches deep, and about 3 inches wide at the surface. It is rolled with two

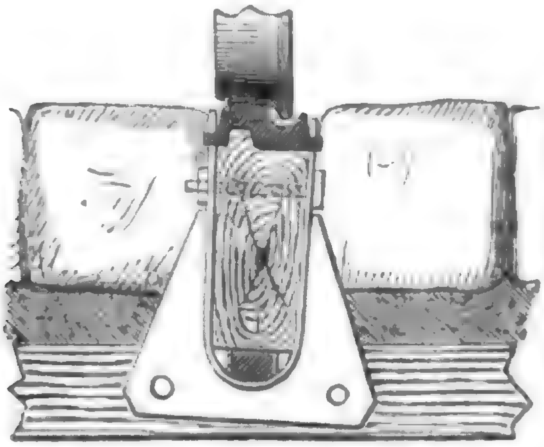

FIG. 144. Versailles Tramways :—Section of Rail, &c., by M. Francq. Scale ⅙.

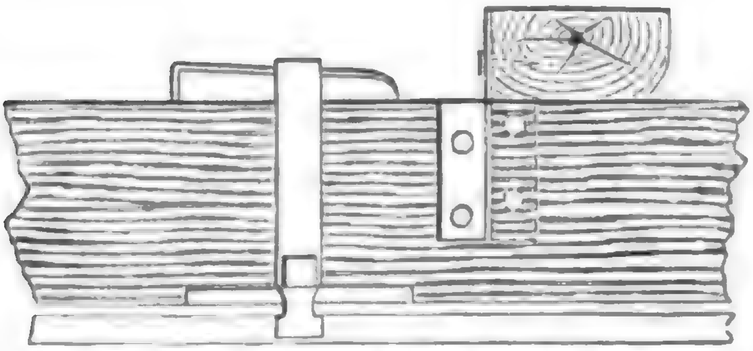

FIG. 145. Versailles Tramways :—Rail, &c., by M. Francq. Scale ⅙.

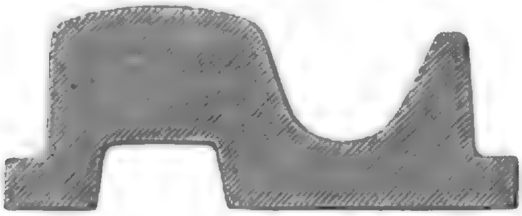

FIG. 146. Section of Versailles Rail, 30½ lbs. per yard. Scale ½

fillets, one at each side, projecting ¼ inch, and making a total width of 3½ inches. The rolling surface was 1 9/16 inches wide, and the groove is 1¼ inches wide; the lower surface, under the tread, is hollowed, and receives in the hollow a corresponding section of the longitudinal sleeper, which is rebated to fit the rail. The longitudinal sleepers are of fir, creosoted; they are 3 inches wide and 7 inches deep, under the soles of the rails. They are slightly inclined inwards, at an angle of 1 in 20, and laid upon transverse sleepers of oak, 6 inches wide and 3½ inches deep, placed at distances of 5 feet apart between centres.

The fastenings are peculiar. The lateral fillets of the rails are notched at intervals of 1 metre, or 40 inches, between centres, to receive the two ends of an iron strap, which is doubled under the sleeper, the ends being correspondingly notched to enter the notches in the fillets, and take a bearing upon the fillets. The ends of the strap are fixed in position by a bolt and nut through the sleeper, and the strap is tightened by a hardwood wedge, driven in under the sleeper.

The longitudinal sleepers are secured to the transverse sleepers by means of a piece of iron plate, bolted to one side of each cross-sleeper, and cut out and flanged to receive the longitudinal sleeper, which is spiked to it.

The objections to this system are, that the fastening of the longitudinal to the transverse sleeper is in sheer, and is not durable; that the rail is too shallow, and is weak; that the means of lateral resistance of the rail to displacement upon the sleeper is insufficient; that the lateral fillets represent a waste of metal, and prevent the close fitting of the pavement to the rail; that there are other projections which are inconvenient in the same way; and that the situation of the wedge for tightening the fastening of the rail—below the sleeper—is inconvenient for purposes of inspection and repair. This system, like many others which have failed in practice, would answer very well if it were a mere fixture, but not for resisting the stress of the rolling movement of heavy bodies.

LILLE.

The tramways of Lille are constructed like level crossings for railways, with two rails and two counter-rails, enclosing at each rail a clear space sufficient for the clearance of the wheel flanges. The rail and the counter-rail (Figs. 147 and 148) are bolted to a cast-iron chair. The chairs are bedded on and screwed down to cross-sleepers laid on the ground, at 5 feet intervals, without any intermediary longitudinal sleepers. The interspace is 1·20 inches wide for the tramcar, as in Fig. 147, but by fixing the counter-rail so that its flat side is presented to the rail, as in Fig. 148, the interspace is increased to 1·80 inches in width, for the traffic of railway waggons.

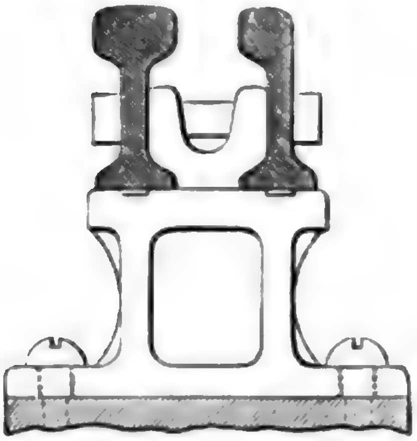

FIG. 147. Lille Tramways:—Section of Rails and Chair, for Passenger Traffic. Rail, 21·7 lbs. per yard. Scale ⅓.

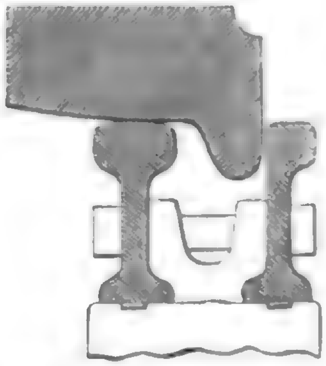

FIG. 148. Lille Tramways:—Section showing arrangement of Rails for Railway Waggons. Scale ⅓.

	lbs. per yard.
Weight of the rail, 3·60 inches deep . . .	28·7
,, counter-rail, 3·60 inches deep . .	22·5
Total weight per yard for each rail .	51·2

The same system—of rail and counter-rail—was adopted in the construction of the Geneva Tramways.

BRUSSELS.—ANTWERP.—LIÉGE.—GHENT.

In Brussels the tramways are worked by four distinct companies, each company having adopted special forms of rail. The oldest line is that between Schaerbeek and the Bois de la Cambre, 4⅜ miles in length, which was completed and opened in 1869. All the other lines have been constructed since 1871. In the end of 1874, the lengths of lines of tramway open in Brussels were as follows :—

	Miles.
Belgian Street Tramway	8¼
Compagnie Brésilienne	6¾
Compagnie des Voies Ferrées Belges (Bois de la Cambre)	4⅜
Compagnie Becquet	3¾
Open in Brussels	23⅛

Gauge of ways, 4 ft. 8½ ins.

In other towns in Belgium there were open as follows :—

	Miles.		Ft.	Ins.
Antwerp	6·16,	gauge	4	5½
Liége	4·78	,,	4	8½
Ghent	4·66	,,	4	8½

making a total length of about 38½ miles of tramway open in Belgium in 1874.

The way was made in double line in the first three tramways of Brussels; the fourth was made with a single way. The tramways in the other three towns were single line, except for a small section of tramway in Ghent.

The sections of rails employed in the tramways of Belgium are shown in Figs. 149 to 159.

The interspace between two lines of way is, in Brussels, 1 metre, or 40 inches; except in narrow streets, where it is only ·8 metre, or 32 inches. At Antwerp it is 1 metre; and at Ghent 1·05 metres, or 42 inches. At Liége it is from 1½ to 1¾ metres, or from 5 feet to

5 feet 9 inches, in view of the clearance required for the passage of railway waggons.

The minimum radius of curvature permitted in any tramway is 44 metres, or 144 feet. At Brussels, the radius is usually from 100 feet to 130 feet; occasionally, for want of space, it is as low as 65 feet, and but rarely as low as 46 feet. At Antwerp the minimum radius is 25 metres, or 82 feet; and at Ghent 15 metres, or 50 feet. At Liége the lower limit is 25 metres, or 82 feet, except for the

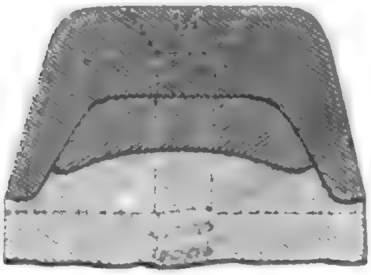

FIG. 149. Belgian Street Railway:—Section of rail laid in suburbs of Brussels, 23 lbs. per yard. Scale ⅔.

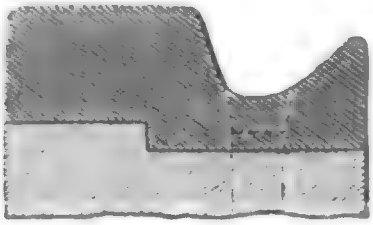

FIG. 150. Belgian Street Railway:—Section of rail laid in Brussels, 24½ lbs. per yard. Scale ⅔.

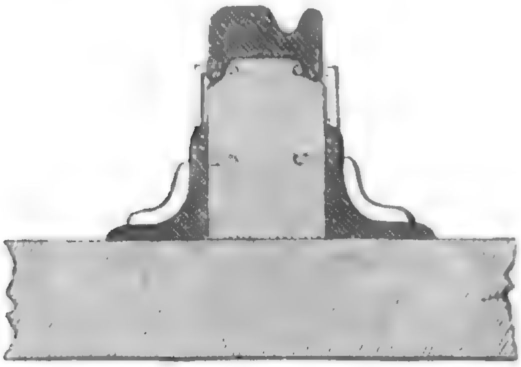

FIG. 151. Voies Ferrées Belges:—Section of rail, &c., 52 lbs. per yard. Scale $\frac{1}{10}$.

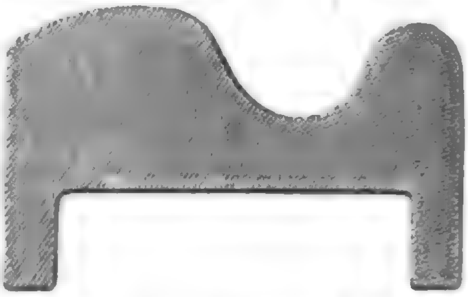

FIG. 152. Voies Ferrées Belges:—Section of rail for straight lines, 52 lbs. yer yard. Scale ⅔.

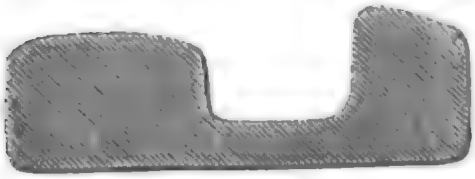

FIG. 153. Voies Ferrées Belges:—Section of inner rail for curves, 36½ lbs. per yard. Scale ⅔.

FIG. 154. Voies Ferrées Belges:—Section of outer rail for curves, 31 lbs. per yard. Scale ⅔.

routes traversed by railway stock, where the radius is not less than 75 metres, or 246 feet.

The way consists generally of grooved iron rails laid on a timber substructure of longitudinal sleepers upon transverse sleepers. The only exceptions to the grooved rails are the rails used in the suburbs of Brussels, and at Ghent, which are formed on the principle of the "crescent" rail, Fig. 17, for which the

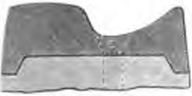

FIG. 155. Compagnie Brésilienne :—Section of rail, 34 lbs. per yard. Scale ⅔.

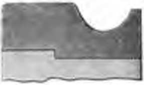

FIG. 156. Anvers :—Section of rail, 30 lbs. per yard. Scale ¾.

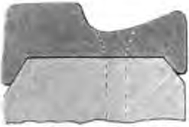

FIG. 157. Tramways d'Ixelles Etterbecq, Brussels (Compagnie Becquet) :—Section of rail, 37 lbs. per yard. Scale ¾.

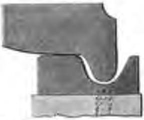

FIG. 158. Liége Tramways :—Section of rail, and tyre of railway waggon, 56 lbs. per yard. Scale ⅓.

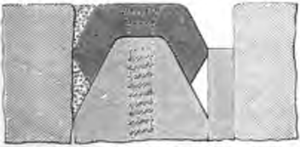

FIG. 159. Ghent Tramways :—Section of rail, &c., 24 lbs. per yard. Scale ⅔.

groove is made by a gap between the rail and the pavement. Sections of the rail are shown in Figs. 149 to 159, in which it is seen that for the most part the rails are fastened to the longitudinal sleepers by vertical screws through the grooves. The only exception is the side fastening, by staples, employed on the "Voies Ferrées Belges," Fig. 151. At Liége the rail is formed with a groove 2 inches in width. The weights of the rails illustrated above are as follows:—

BELGIUM, WEIGHT OF RAILS PER YARD.

	lbs.
Brussels:—	
Belgium Street, suburbs	23
„ „ in town	24½
Voies Ferrées Belges	52
Brésilienne	34
Compagnie Becquet	37
Antwerp	30
Liége	56
Ghent	24

The length of tramway in Brussels open in the end of 1876 amounted to 45,312 metres, or 28 miles. The number of cars in service on all the lines was 84, and of horses 750. The working expenditure may be calculated approximately on the following basis:—

	Total cost per day. s. d. s. d.	Miles travelled per day.
1 horse	3 7 to 4 0	12 to 19
1 car	16 0 „ 20 0	60 „ 80

These costs include the whole of the working expenses.

The first cost of Brussels tramways has been approximately as follows:—

COST OF TRAMWAYS IN BRUSSELS.

Way, single line	£1,270 to £1,600 per mile.
Horses, including harness and accessories	£48 per horse.
Cars in service, including accessories	£360 per car.
Stables, sheds, offices, workshops, &c., per horse, effective, or on duty	£80 to £100 per horse.

CONSTANTINOPLE.

The tramways of Constantinople, of which M. Lebout was the engineer, were constructed with the pattern of grooved rail, weighing 46 lbs. per yard, employed in the Paris tramways, fastened as in Fig. 160. The rails were bolted to longitudinal sleepers, laid on a bed of sand 8 inches deep, spread on the bottom of the excavation. The longitudinal sleepers were connected by round

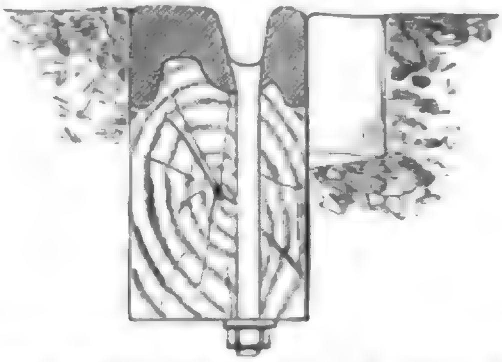

FIG. 160. Tramways of Constantinople:—Section of rail, &c., 46 lbs. per yard. Scale $\frac{1}{4}$.

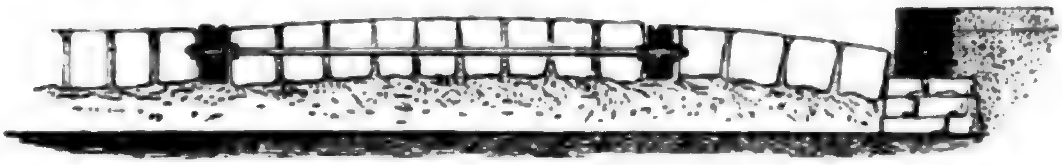

FIG. 161. Tramways of Constantinople:—Section of half-width of street and way. Scale $\frac{1}{40}$.

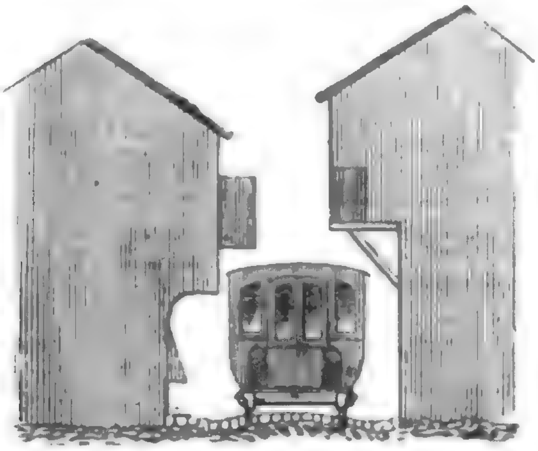

FIG. 162. Tramways of Constantinople. Section of a narrow street, with a single line of way. Scale $\frac{1}{20}$.

iron tie-rods, which were passed through them, and were screwed up by nuts at both ends of the sleepers, as shown in the section of the way, Fig. 161. Streets of from 13 feet to 23 feet wide were paved all the way across, as shown in Fig. 162.

The rails and their accessories were, according to M. Goschler, before quoted, supplied from the Terrenoire Works, France, delivered at Constantinople, at the following prices:—

CONSTANTINOPLE TRAMWAYS.

	Per ton.		
	£	s.	d.
Rails and fishes . . . . . £10 1s. 6d. and	10	17	6
Bolts	23	15	6
Washers	31	16	6
Tie-rods, 2 metres or 6·56 feet apart	33	9	0

The weight of material per yard of single way was as follows:—

	Per lineal yard of way. lbs.
Rails, per yard, 46 lbs.	92
Fishes for rails, 5 lbs. each	1·5
,, for longitudinal sleepers, 1½ lbs. each .	1·38
Bolts, ½ lb. each	1·84
Tie-rods, 13¼ lbs. each	3
Total per yard of single way	100 lbs.
Total if tie-rods are 2 metres or 6·56 feet apart	103 lbs.

	s.	d.	
Cost of laying way, including carriage and maintenance for one year	2	5	per yard.
Cost of laying pavement	3	7½	,,

Mr. Goschler gives an analysis of the accounts of the Constantinople Tramways for 1872, which contains many instructive details.*

* "Les Chemins de Fer Nécessaires," *Compte Rendus de la Société des Ingénieurs Civils*, 1873, page 366.

Moscow.

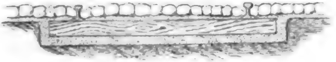

FIG. 163. Moscow Tramways:—Section of line. Scale $\frac{1}{44}$.

The first section of the tramways of Moscow was opened in August, 1874; and in 1875 a total length of 60 miles of tramway was opened for traffic. The way was designed by the engineer of the tramways, Colonel Sytenko, who commenced by rejecting the grooved rail, and adopted the Vignoles type of rail, laid on transverse sleepers, Figs. 163 and 164. The rails are of steel, from the works at Creusot, weighing 36 lbs. per yard; they are made to a height of 5 inches, to admit of the juxtaposition of paving stones of sufficient depth above the sleepers. The paving stones next the rails at the inner sides are cut to form a groove for the wheel flanges. Counter-rails, it appears, have only been found necessary at the points and crossings. The rails are laid to a gauge of 5 feet, upon sleepers placed at intervals of 4 feet 3 inches. It is believed—and it is likely—that, on this system of way, the tractive force required is a half less than that required for the ordinary grooved rail.

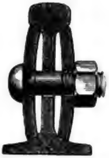

FIG. 164. Moscow Tramways:—Section of rail and fish-joint, 36 lbs. per yard. Scale $\frac{1}{4}$.

Leipzig.

The first section of the Leipzig tramways, consisting of the Promenade line round Liepzig and branches to Rendwitz and Connewitz, together about 6 English miles in length, was opened on May 18, 1872. The line to Lindenau was opened in September of the same year, making in all 8⅔ English miles of way open for traffic in 1872. There are now altogether five lines open, of an aggregate length of 11·30 miles.

The rails are laid to a gauge of 4 feet 8½ inches, on what is known as the Vienna system, which is, in fact, similar to Loûbat's way, already described, page 296. The rails are of iron, and they weigh 30 lbs. per yard. They are 3 inches wide, and are formed with obliquely-faced flanges, as shown in Figs. 165 and 166. They are laid on longitudinal timber sleepers, which are remarkable for their deep and narrow scantlings,—8 inches deep and 2¾ inches wide. They are chamfered to receive the rails, which are fastened to them by 4½-inch spikes, passed through holes punched in the flanges. The longitudinal sleepers are laid on and notched into transverse sleepers, 7 inches wide, 5 inches deep, and 6½ feet in length, placed at intervals of 6 feet between centres, and laid in ballast. The longitudinal sleepers are secured to the cross-sleepers by oak wedges. When the line passed through streets already paved, the pavement was renewed for the whole width. On macadamised roads only a narrow strip of paving was laid on each side of the rail.

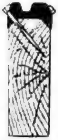

FIG. 165. Leipzig Tramways :—Section of rail, &c. Scale ⅛.

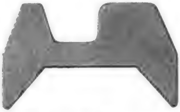

FIG. 166. Leipzig Tramways :—Section of rail, 30 lbs. per yard. Scale ½.

CASSEL.

The Cassel Tramway was opened on July 9th, 1877, to be worked by steam locomotives, supplied by Messrs. Merryweather and Sons. The section of rail is shown in Fig. 167, with the section of the wheel-tyres of the locomotives.

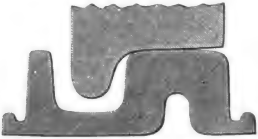

FIG. 167. Cassel Tramway :—Section of rail and wheel-tyre. Scale ½.

LISBON.

A concession was secured, in 1873, by Messrs. Edwin Clark, Punchard & Co., for the construction and working of a system of tramways in Portugal, 51 miles in length, from Lisbon to Cintra, for passenger traffic, and from Lisbon to Torres Vedras, for goods and wine traffic chiefly. The tramways were made a single line, laid on common roads; they were to be worked by tank locomotives, with trains of passenger cars and of goods cars, at a speed of 15 miles an hour. The ruling gradient was 1 in 20, and the quickest curves were of a radius of 25 feet.

The way consisted of three parallel rails, laid on transverse sleepers. The central rail was an iron flat-footed rail, weighing 36 lbs. per yard, spiked to the sleepers. The outer rails were wooden trams of oak, 8 or 9 inches wide, and 3 inches deep, laid to a gauge of 4 feet 2 inches between centres. The cross-sleepers were alternately long enough to take all the rails, and short enough to take only the middle rail. The engine and the train were guided by the central rail; the weight of the train rested on the central rail, whilst the greater portion of that of the engine rested on the wooden trams, through the driving wheels.

The engines had two steam cylinders, 11 inches in diameter, with a stroke of 18 inches; the driving wheels were 3 feet 9 inches in diameter, by 14 inches wide at the tyres. The working pressure in the boiler was 140 lbs. per square inch. The engine was carried by two bogies, one before and one behind, arranged as bicycles, running on the central rail. The distance between the centres of the bogies was 13 feet. The weight of the engine, empty, was 11 tons 1½ cwt., and, in working order, 13¼ tons, of which 8½ tons was available as driving weight. According to Mr. Curry,* these engines were capable of taking a train of six passenger carriages, with 132 passengers, weighing altogether 22½ tons, up an incline of 1 in 20. The heaviest goods train, taken up the same incline, consisted of six waggons, weighing, with goods, 28½ tons.

It appears that these tramways have been abandoned.

WELLINGTON CITY TRAMWAYS, NEW ZEALAND.

In the design of these tramways, Fig. 168, constructed in 1878, to a gauge of 3 feet 6 inches, it seems that the best results of experience in Europe and America have been ignored. The rail is a flat bar, 3½ inches wide, 1⅛ inches thick, grooved to a depth of ¾ inch, and leaving only ⅜ inch thickness of metal under the groove. The rail is spiked through the groove to a longitudinal sleeper 4 inches wide and 6 inches deep. The longitudinal sleepers rest on transverse sleepers, 6 inches wide by 4 inches deep and 5 feet long, placed at distances of 3 feet 5 inches apart between centres. The cross-sleepers are fastened to the longitudinal sleepers with a small knee on each side, and one spike each way.

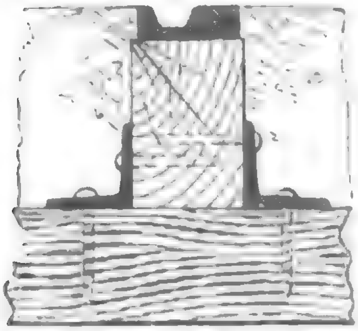

FIG. 168. Wellington City Tramways: — Section of rail, &c. Scale ⅛.

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* "The Lisbon Street Tramway," a paper read March 6, 1874, at the Institution of Civil Engineers, by Mr. Matthew Curry, jun., Stud. Inst.C.E.

BUENOS AYRES TRAMWAYS.—LIVESEY'S METAL WAY

Mr. James Livesey, so early as in 1869, advocated the employment of an iron substructure for tramways, constructed on the principle of the modern railway, with intermittent bearings, substituting for the continuous wood-sleeper system, with the objectionable vertical spike fastenings then in vogue, a rail of sufficient stiffness supported on and solidly and simply fixed to cast-iron bearings or stools at intervals. In his patents of that year he showed several varieties of iron and steel tramway, of which two kinds, shown in Figs. 169 to 172, were laid to a gauge of 4 feet 8½ inches, in the city of Buenos Ayres, the first section having been opened in October, 1870.

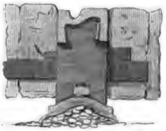


FIG. 169. Buenos Ayres Tramways:—Livesey's Steel Rail System. Scale ¼.

The steel grooved rail, Figs. 169 to 171, was employed for the city lines. It weighed 40 lbs. per yard, and it was rolled in lengths of 24 feet. It was 3½ inches wide, and 2⅜ inches deep at the rolling side, being formed with deep flanges, so as to derive the practical maximum of strength from a given quantity of material. The tread was 1¾ inches wide, the groove is 1⅜ inches wide and $\frac{11}{16}$ inch deep. The width of the groove is more than is usual in English tramways, but the width is not inconveniently great, as the narrowest wheel tyres of common road vehicles at Buenos Ayres

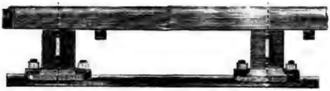


FIG. 170. Buenos Ayres Tramways:—Livesey's Steel Rail System. Scale $\frac{1}{20}$.

are 3 inches in width. The least thickness under the tread is ¾ inch, and at the sides 7/16 inch.

The rails were laid on stools at distances of 3 feet apart between the centres, except at the joints of the rails, where an extra stool was placed under the joint. The stools are bolted to baseplates of wrought iron, corrugated, two stools to each baseplate, except at the joints, where there were three stools on the baseplate. The baseplates are 4 feet 6 inches in length, 5½ inches wide, and ½ inch thick. The stools were each 3½ inches long, and afforded a bearing of that length for the rail. The rail was rolled so as to form a dovetail with the stool, and by means of wedge-shaped keys it was firmly held down. At the joint, the rails were fixed to the chair by two wedge-headed bolts and nuts. The sides of the rail were flush with those of the stools, and together they offered vertical walls for the close abutment of the pavement. Mr. Livesey was of opinion that in dealing with such hard and rigid materials, wrought iron is preferable to cast iron as a material for the base, and that, on the contrary, cast iron is preferable to wrought iron for the standards or stools, since the greater mass of cast iron absorbs the blows of the traffic, and does not impart, like wrought iron, a tremulous movement to vehicles. The rails were tied to gauge by wrought-iron tie-bars, 1½ inches deep and ⅜ inch thick, at distances of 3 feet apart. They passed through the stools and were notched to fit into them, and keyed into position.

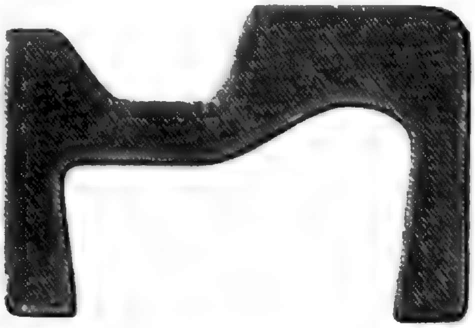


FIG. 171. Livesey's Steel Rail. Scale ½.

The quantities and costs at current prices (July, 1877) were as follows:—

LIVESEY'S GROOVE-RAIL TRAMWAY, PER MILE, SINGLE LINE.

	Tons.
440 lengths of steel grooved rails, 24 feet long, at 40 lbs. per yard	63
440 × 4 = 1,760 wrought-iron baseplates, 22½ lbs. each	17·75
440 × 8 = 3,520 cast-iron stools, 9½ lbs. each 440 ,, joints, 15 lbs. ,,	18
440 × 4 = 1,760 wrought-iron tie-bars, 10¼ lbs. each	8
1,760 × 2 = 3,520 cotters, 6 ozs. each	0·60
3,520 + 440 = 3,960 × 2 = 7,920 base bolts, 7 ozs. each	1·60
3,520 wrought-iron bent keys, 1¼ lbs. each	2
440 × 2 = 880 wrought-iron joint bolts, 1 lb. each	0·40
Total weight per mile, single line	111·35

Taken at £9 per ton, in the gross, the cost for the material amounts to £1,002 per mile.

The tramways which have been made with timber substructures in Buenos Ayres, have been taken up and replaced by iron structures.

The second kind of tramway, Fig. 172, used in the suburban districts of Buenos Ayres, has a flanged, or Vignoles' rail, such as is used on railways, except that it is rolled with the flange narrower at one side than at the other, to admit of the paving sets at the outer side being laid close to the head of the rail. The extra width of flange at the inner side determines the width of the groove in the pavement for wheel flanges, and it acts as abutment for the contiguous paving sets. The rail is placed on a cast-iron stool, to which it is fixed by a hook bolt and nut; the stool is bolted to a flat wrought-iron baseplate, which rests on the foundation. The stools are tied to gauge by means of cross-bars and cotters.

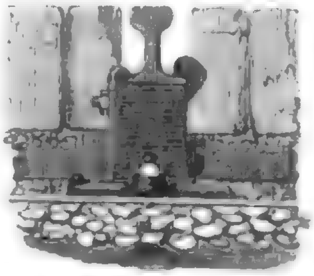


FIG. 172. Buenos Ayres Tramways:—Livesey's Iron Rail System. Scale ⅛.

There have been nearly 100 miles of tramway laid on Mr. Livesey's system in the city of Buenos Ayres. This may be called the City of Tramways, where a tramway runs down nearly every street.

In this connection, it may be noted that Mr. Livesey, in his patent of February, 1875, describes a method of maintaining the stone sets of the pavement next the rails at the same level as the rails. The rail is laid on a longitudinal sleeper, which rests on "a flat plate sufficiently wide to project under the first row of stones on each side of the rail."

COCKBURN-MUIR'S IRON WAY.

Mr. W. J. Cockburn-Muir patented, in November, 1870, a system of iron way, for railways, light railways, and tramways, of simple design, which he calls the "block sleeper" system, in which the rail is supported at regular intervals on cast-iron stools or blocks. It is shown in Figs. 173, 174, 175, as employed for tramways. The rails are of wrought iron, rolled in lengths of 21 feet; they are formed with the ordinary groove on the upper side, and with a vertical web on the underside, to impart to the rails the needful vertical strength between the bearings; they weigh 30 lbs. per yard, and are 3 inches in width. The sleepers are cast-iron blocks, rectangular, hollow, open at the base, and ribbed interiorly. They are about 11½ inches long, 7½ inches wide, and 6 inches deep, outside dimensions; and, for ordinary traffic, they are laid at 3 feet 6 inches apart between centres. The span between the sleepers is only 2 feet 6½ inches. They are laid upon the floor of the excavation, or upon a prepared bed of concrete. In laying they are turned upside down, filled with gravel or coarse sand, and closed with a hand board, then returned into place when the board is slipped out. The weight of one block is from 43½ lbs. to 48 lbs., according to the nature of the traffic. The blocks are chequered on the upper surface to give foothold; they act as paving sets, and are integral portions of the paving of the streets. As the sleepers alternate with the stone sets next the rails at each side, the formation of ruts or furrows at the sides of the rail is prevented.

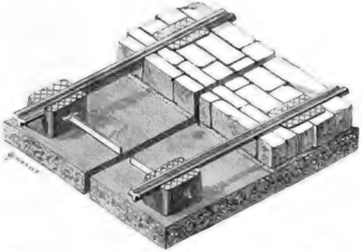


FIG. 173. Cockburn-Muir's Iron Way at Monte Video, &c.

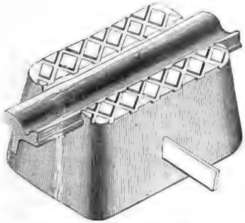


FIG. 174. Cockburn-Muir's Iron Way :—View of sleeper and rail.

The rails are rolled with a fillet on the outer side to fit into a corresponding groove in the recess of the blocks. The recess is formed to receive the rail, which fits it exactly, except at the outer side of the rail, where a key or wedge of cast iron, 13 inches long, is driven, taking a bearing for the whole length of the block, and fixing the rail to the block. As the rail rests solidly on the block for its whole length, the key also acts as a fish at the joints of the rails, and the actual span of the rail is reduced to the distance between the sleepers, or 2 feet 6½ inches.

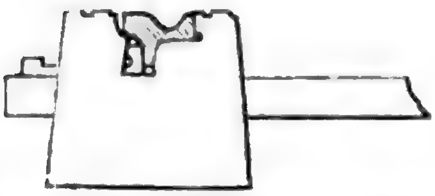


FIG. 175. Cockburn-Muir's Iron Way:—Rail, sleeper, and fastenings. Scale 1/12.

The sleepers are connected transversely, and tied to gauge, by wrought-iron bars, which are passed right through the blocks, into which they are keyed at the outer side.

The depth of the sleepers affords space for a ½-inch bed of sand, and paving sets 5½ inches deep.

Mr. Cockburn-Muir's system was adopted for all the tramways at Monte-Video. It is also in use at Buenos Ayres, Salto, and Bahia, and short lengths have been laid at Vienna and Palermo. At Monte-Video the gauge of one of the lines is 4 feet 10⅝ inches, and that of all the others is 4 feet 8½ inches. At Bahia one part of the line is laid to a gauge of 4 feet 8½ inches, and another part to a gauge of 2 feet 5½ inches. At other places this system has been adopted on a gauge of 4 feet 8½ inches.

The quantities of iron per single mile of 4 feet 8½ inches gauge are as follows:—

W. J. COCKBURN-MUIR'S TRAMWAY, PER MILE, SINGLE LINE.

	Tons.	Cwts.	Qrs.
Rails, wrought iron, at 30 lbs. per yard	47	3	0
830 tie-bars, at 7¼ lbs. each	2	13	3
1,660 cotters for tie-bars, at 0·15 lb. each . . .	0	2	1
3,018 block sleepers, at 43½ lbs. each.	58	12	1
3,018 wedge keys, at 2½ lbs. each	3	7	2
Total weight	111	18	3

The cost of the materials complete amounted (1877) to about £870 per mile, single line.

Portions of Mr. Cockburn-Muir's rail, weighing 30 lbs. per yard, were tested by Mr. Kirkaldy, as the rolling proceeded, for transverse strength, at the rate of one sample for every 100 rails. The test rails were laid on a span of 2 feet 7½ inches between the supports, and they were tested by loads applied at the middle. The following are average results of tests of ten specimens of rail:—

Total load applied,	5,000 lbs. or 2·23 tons.	6,800 lbs. or 3·03 tons.
Deflection,	·16 inch ,, ,,	·60 inch.
Set	·01 ,, ,, ,,	·41 ,,
Elastic limit of load		5,200 lbs. or 2·32 ,,
Ultimate load applied		9,073 lbs. or 4·05 ,,

All the specimens were removed unbroken. Mr. Cockburn-Muir stated that the greatest weight which in practice comes upon the rail does not exceed 3,500 lbs., or 1·12 tons. This is just half the elastic strength of the rail.

After having been down in Buenos Ayres upwards of ten years, Mr. Cockburn-Muir's way stood well, and gave great satisfaction. The manager of the tramways there, Mr. H. W. Ford, reported in September, 1880, that having during the preceding two years watched the working of three miles of this way, the Puente Ulsina line, laid on a very bad road, together with other lengths in the city streets, he arrived at the conclusion that this was "the best horse tramway in that part of the world." The block sleepers, he added, stood remarkably well, and were easily packed; they resisted, without harm, the blows of the heavy ox-carts, and one reason for their stability is no doubt to be found in the block-and-key combination, which constitutes "an efficient equivalent for fish-plates, keeping the rail joint stiff and true."

Subsequently, Mr. Cockburn-Muir, at the instance of others, adopted steel for the material of his rails, selecting Siemens steel, for extensions of the lines of tramway in Monte-Video. The Lima tramways also were constructed with Siemens steel rails on this system. These steel rails, weighing 30 lbs. per yard, and measuring 3·05 inches in extreme width, and 2·35 inches in depth, have been tested for transverse strength. They were tested in lengths of 3½ feet, laid on supports at a distance of 2 feet 7½ inches apart. The best of five samples yielded the following results:—

Stress at the middle.	Deflection (steel rail).
5,000 lbs.	·12 inch
7,000 ,,	·19 ,,
10,000 ,,	·33 ,,
11,300 ,,	·43 ,,
12,500 ,,	·62 ,,
15,000 ,,	1·21 ,,
17,500 ,,	2·69 ,,
19,164 ,, or 8·55 tons (ultimate stress)	5·79 ,, (broken).

Plotting these deflections as ordinates to a base line representing the stresses, and drawing a curve through the ends, it appears that the yielding point of the curve corresponded to a stress of 9,000 lbs., or 4 tons, at the middle, where the deflection was ·25 inch. This load of 4 tons should be taken as the measure of the elastic limit of strength. But Mr. Cockburn-Muir prefers to fix the limit at the stress under which permanent set commences to take place, which in this instance amounted to 11,300 lbs., or 5 tons, when the deflection was ·43 inch. The average results for the five samples which were tested, when permanent set began, were as follows:—

Elastic limit of load, according to Mr. Cockburn-Muir . . . . . 10,320 lbs. or 4·61 tons
Maximum deflection without permanent set ·40 inch.
Ultimate load . . . . 17,766 lbs. or 7·93 tons.
Deflection.—3 rails remained unbroken at 6 inches of deflection; 2 rails were broken at 5·8 inches of deflection.

The maximum weight, 1·12 tons, or 2,500 lbs., that could be placed on the rails when in place at their destination, leaves ample margin of strength. The deflection under that weight at the middle does not exceed ·06 inch, $\frac{1}{16}$ inch, when the rail is free on the supports. But, regarding the rail as a continuous beam, as it practically is, when keyed into the block sleepers, the deflection must be something less than a fourth of this, or $\frac{1}{64}$ inch. This, it is needless to add, makes a sufficiently stiff way for the locality.

Where the general traffic of the street is heavier than the limit above stated, of course the rail should be proportionately stronger. But there is a plentiful reserve of stiffness in Mr. Cockburn-Muir's way, which is attributable, not only to the compactness of the rail in section, but in great measure to the scope and firmness of the fastenings.

To compare these steel rails with the iron rails of the same section and weight, 30 lbs. per yard, already noticed, the following are corresponding results of tests for transverse strengths of ten samples of iron rails. The results for the best samples were as follows. On bearings 2 feet 7½ inches apart, loaded in the middle :—

Stress at the middle.		Deflection (iron rail).
3,800 lbs.		·09 inch
4,000 ,,		·10 ,,
4,200 ,,		·11 ,,
4,600 ,,		·13 ,,
5,000 ,,		·14 ,,
5,600 ,,		·17 ,,
5,650 ,,	Elastic limit, according to Mr. Cockburn-Muir.	
6,000 ,,		·23 inch
6,600 ,,		·35 ,,
7,000 ,,		·48 ,,
7,600 ,,		·76 ,,
8,000 ,,		·98 ,,
9,094 ,, or 4·06 tons	ultimate stress	6·00 ,, (unbroken)

The average results, already given, for the ten samples, are here repeated for the sake of comparison.

Elastic limit of load, according to Mr. Cockburn-Muir	5,200 lbs. or 2·32 tons.
Maximum deflection without permanent set	·16 inch.
Ultimate load	9,073 lbs. or 4·05 tons.

The average elastic limits given for the iron rails and the steel rails respectively are 5,200 lbs. and 10,320 lbs., whilst the corresponding deflections without permanent set are ·16 inch and ·40 inch, indicating that whilst the elastic strength of the steel rails is double that of the iron rails, the deflection is more than double, and that the stiffness of the steel rail is practically not more than that of the iron rail. Under the medium stress, 5,000 lbs., or 2¼ tons, the deflections are respectively ·14 inch and ·12 inch for iron and steel, showing, in practice, equal stiffness.

The weight of metal in Mr. Cockburn-Muir's way has already been given. It remains the same with the steel rail of 30 lbs. per yard, making 111 tons 18¾ cwt. per mile, single line, the cost of which at current prices (March, 1881) amounted to about £900 per mile, averaging about £8 per ton.

MANNHEIM AND LUDWIGSHAFEN.—DE FERAL'S IRON WAY.

The iron way of M. de Feral consists of a girder-rail laid on wrought-iron sleepers, with clip-fastenings. It was first laid at Metz, by M. Feral, for a length of 8⅛ miles, opened in October, 1876; then at Ludwigshafen for a length of 6⅞ miles, opened in May, 1878; at Leiden, for a length of 5 miles, opened in November, 1879; and at Antwerp, for a length of 3¾ miles, opened also in November, 1879.

The flange-rail and the base-plate, shown in section, Fig. 176, are both of rolled iron. The rail weighs 23 kilogrammes per metre, or 46⅛ lbs. per yard, and is rolled in lengths of 6½ metres, or 21 feet 4 inches. They are 15 centimetres, or 5·9 inches, deep. The head of the rail is $2\frac{5}{16}$ inches wide, of which the tread is $1\frac{7}{16}$ inches in width, and the remainder is a horizontal flange projecting from the base of the head to form a groove in conjunction with the paving stones. The flange-base is 3 inches wide. The base and the web average 9 millimetres, or ·35 inch in thickness. The fish-plates are 8 inches long, and $\frac{7}{16}$ inch thick, and are fixed with four $\frac{9}{16}$-inch bolts and nuts, two deep.

The base is not continuous, but consists of rolled iron ribbed-plates, ·35 inch in thickness, 11¾ inches wide, having three vertical ribs on the lower side; making the total depth of the base 2¼ inches. These are similar in section to the Hilf sleeper laid in Continental railways, and they take a secure hold of the subsoil. They are about 8 inches long intermediately, and about 11¼ inches long at the joints. The rails are fixed to the bases by means of clips riveted at one side of each chair, and bolted at the other. The bases are laid at distances of 5 feet 4 inches apart between centres.

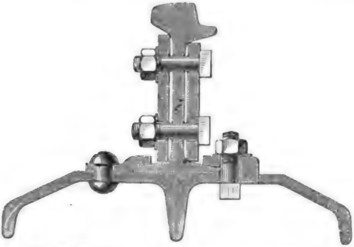


FIG. 176. De Feral's Way, Mannheim, Ludwigshafen. Scale ¼.

The iron sleepers are simply laid in the bottom of the space cleared for the way. There is not any other preparation or foundation.

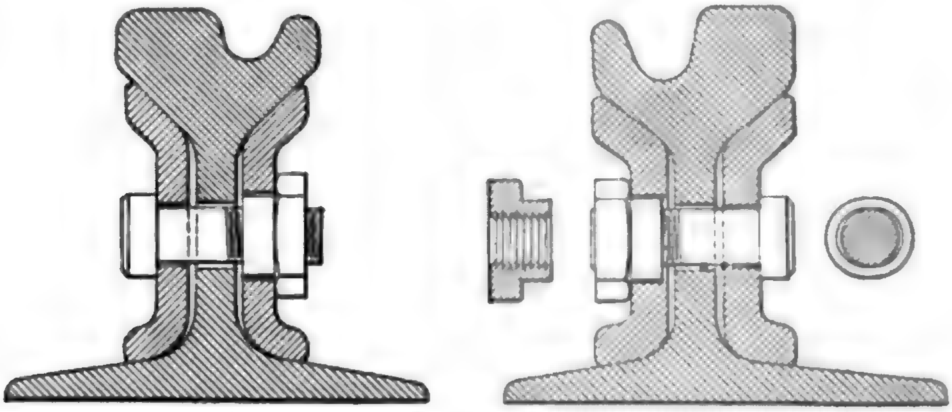
APPROXIMATE QUANTITIES PER MILE, SINGLE LINE, OF DE FERAL'S WAY. 1878.

Iron Rails, 46 lbs. per yard	73	tons
Base-plates :—496 joints @ 22 lbs.	4·9	,,
1,488 intermediates @ 13 lbs. . .	8·6	,,
Fish-plates, 496 pairs @ 7¼ lbs. per pair (bolts extra)	1·6	,,
Tie-rods, 744 at 4½ lbs. each	1·5	,,
Total weight . . .	89·6	tons.

Here follow notices of three South American tramways of recent design, in which the girder rail is employed:—

CITY OF BUENOS AYRES TRAMWAYS
(Mr. Edward Woods, Engineer).

Original Section.—The girder rails, Fig. 177, are of steel, weighing 103 lbs. per yard. They stand 6½ inches high, 6 inches wide at the base. The webs of the rails are ⅝ inch thick; the heads are 3⅞ inches wide, and the grooves are 1 inch wide. The fish-plates are ½ inch thick, 18 inches long, weighing 22 lbs. per pair, and fastened with four ⅞-inch bolts and nuts. The maximum length of the rails is 27 feet, for each pair of which there are five cross iron tie-bars, 2 inches by ½ inch, slotted and fixed with cotters.



FIGS. 177 and 178. City of Buenos Ayres Tramways:—Sections of rail and fastenings. Scale ¼.

Amended Section, Fig. 178.—A slight addition to the weight of the rails was made, to the extent of 3 lbs. per yard, making a total of 106 lbs. per yard. The fish-plates were extended to a length of 24 inches, and to $\frac{9}{16}$ inch thick, or $\frac{1}{16}$ inch thicker than the original plate; and there are six bolts and nuts to each pair of fishes. The weight of fish-plates was thus augmented to 36 lbs. per pair.

The quantities per mile of way, single line, are as follows:—

CITY OF BUENOS AYRES TRAMWAYS.—QUANTITIES OF WAY, SINGLE LINE.

		Original section.	Amended section.
Rails . .	Weight per yard	103 lbs.	106 lbs.
	,, ,, mile	tns. cts. q. lbs. 161 17 0 16	tns. cts. q. lbs. 166 11 1 20
Fish-plates .	Weight ,, pair	22 lbs.	36 lbs.
	Pairs ,, mile	400	400 pairs
	Weight ,, ,,	tns. cts. q. lbs. 3 18 2 8	tns. cts. q. lbs. 6 8 2 8
Fish-bolts .	Weight ,, bolt	1 lb.	1 lb.
	Number ,, mile	1,600	2,400
	Weight ,, ,,	cts. q. lbs. 14 1 4	tns. cts. q. lbs. 1 1 1 20
Tie-bars . .	Weight ,, bar	16 lbs.	16 lbs.
	Number ,, mile	1,000	1,000
	Weight ,, ,,	tns. cts. q. lbs. 7 2 3 12	tns. cts. q. lbs. 7 2 3 12
Tie-bar cotters	Weight ,, cotter	½ lb.	½ lb.
	Number ,, mile	4,000	4,000
	Weight ,, ,,	cts. q. lbs. 17 3 12	cts. q. lbs. 17 3 12

TOTAL WEIGHT OF MATERIALS PER MILE.

	tns.	cts.	q.	lbs.	tns.	cts.	q.	lbs.
Rails . . .	161	17	0	16	166	11	1	20
Fish-plates . .	3	18	2	8	6	8	2	8
Fish-bolts . .	0	14	1	4	1	1	1	20
Tie-bars . . .	7	2	3	12	7	2	3	12
Cotters . . .	0	17	3	12	0	17	3	12
Tons . .	174	10	2	22	182	2	0	16

The cost of the material, according to the amended section, as above, per mile of way, delivered in Antwerp, was, in 1891, £1,200.

TESTS FOR RAILS OF THE AMENDED SECTION.

The rails were tested by Mr. Woods in the following manner:—

1*st*. *By Falling Weight.*—A piece of rail 10 feet long was placed on bearings 3 feet 6 inches apart centre to centre, and a weight of 1 ton was allowed to fall on its middle point. The first blow was from a height of 10 feet; the second 15 feet, and the third 20 feet. The average amounts of bending produced by these blows were:—

For 1st blow 1·56 inches.
" 2nd " 3·29 "
" 3rd " 5·55 "

2nd. By Pressure Tests.—A piece of rail 10 feet long was placed on bearings 3 feet 6 inches apart, centre to centre, and pressure was applied at the middle point. The following were the average results:—

Central pressure. Tons.	Average deflection. Inches.	Average permanent set. Inches.
20	0·054	0·0
25	0·064	0·0
30	0·101	0·0
35	0·134	0·0
40	0·187	0·024

3rd. By Tests for Tensile Strength and Ductility.—The average tensile strength per square inch of original section was 33·15 tons.

The average reduction of area at the place of rupture by tensile stress was 49 per cent. of the original section.

BUENOS AYRES GRAND NATIONAL TRAMWAY.

Sir George B. Bruce, the engineer of this tramway, employed girder-rails, weighing 75 lbs. to 77 lbs. per yard, bedded on concrete. The rails, Fig. 179, are 6 inches high, and 6 inches wide at the base, in lengths of 30 feet. The web is $\frac{5}{8}$ inch thick; the head is $2\frac{7}{16}$ inches wide; the groove is 1 inch wide. The joints are fished with two plates $\frac{7}{16}$ inch thick, 16 inches long, with four

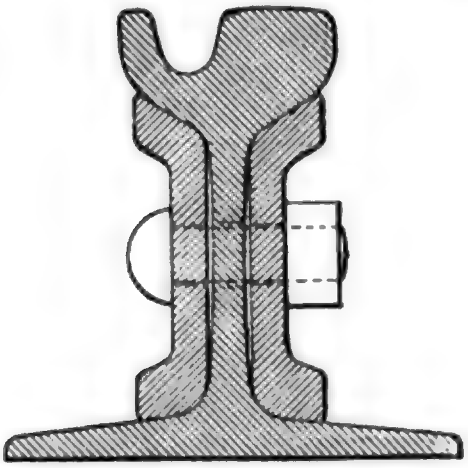


FIG. 179. Buenos Ayres Grand National Tramway: Section of Rail and Joint. Scale $\frac{1}{4}$.

¾-inch bolts and nuts. The rails are tied to gauge with slotted tie-bars 1¾ inches by 7/16 inch, with cotters, of which there are six for each 30-feet rail, at 5 feet intervals. The gauge is 4 feet 8½ inches. The surface is paved with granite sets.

LA PLATA TRAMWAYS.

The girder-rail, Fig. 180, designed by the engineer of La Plata Tramways, Sir Douglas Fox, weighs 75 lbs. to 76 lbs. per yard. They are 6 inches high, 5⅞ inches wide at the base, with ⅜-inch webs. The head is 2⅞ inches wide, with a groove 1 inch wide. The fish-plates are of ½-inch metal, with ¾-inch bolts and nuts.

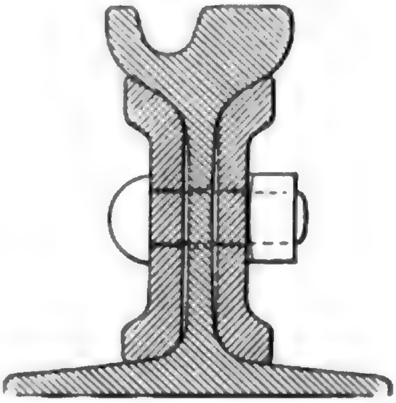


FIG. 180. La Plata Tramways: —Section of rails and fastenings. Scale ¼.

AMERICAN PRACTICE.—HIGH GIRDER RAIL, PHILADELPHIA TYPE.

This rail, Fig. 181, is an adaptation of the Philadelphia, or step rail, already noticed, to the girder rail. The rail is 9 inches high, 5 inches wide at the base; the step is 1⅛ inches high, and the total width of the head is 5¼ inches. The web of the ordinary girder-rail is usually pared down to a thickness of from ¼ inch to 7/16 inch. So far, it has been noted, none of the leading patterns of girder rail has failed in consequence of being too thin.

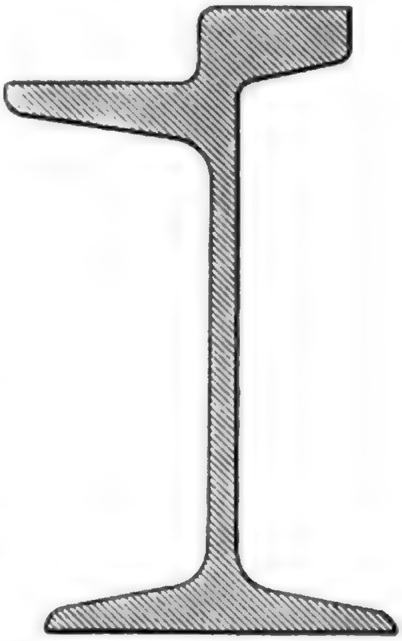


FIG. 181. High Girder Rail. Philadelphia type. Section.

CHAPTER XXVII.

THE GIRDER RAIL.

THE girder rail was originally invented and patented by Mr. Charles Burn, in October, 1860, according to the section, Fig. 182, which is well proportioned, and is, in fact, a modification of the Vignoles rail for railways. It was re-invented and patented by M. Achille Legrand, of Paris, in January, 1877, according to the section, Fig. 183. Mr. J. Gowans patented, in July, 1878, a modification of the girder rail, Figs. 35, 36 (pp. 132, 133), in which the base flange is wider at the outer side, under the tread, than at the inner side. Openings were made through the web of the rail at short intervals, in order to lighten the rail, and to admit of the binding of the concrete packing through the rail. This rail was tried experimentally in Edinburgh in 1877—78, and in Dundee in 1879.

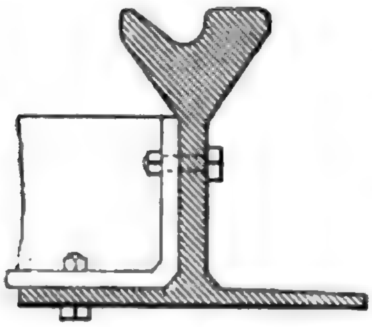


FIG. 182. Burn's Girder Rail. Section.

Although the girder rail was not in any sense the invention of Mr. Gowans, yet to him belongs the merit of introducing and testing the girder type. By the rule of experience it has been made evident that built-up rails—rails constructed of two or more pieces—are not suited for tramway service, especially with steam locomotion; and that, like railway rails, it is necessary that they should be rolled as one piece. The tramway girder rail is a clear instance of the survival of the fittest; although, singular to say, it was, as above noted, announced to the world nearly twenty years before it was brought into practical use.

Though the foregoing evidence, supplied by a few leading tramways in favour of the girder rail, led up to the employment of the girder rail in the case of the Glasgow Tramways, the Kincaid Tramways, and the Manchester Tramways, there is a notable exception in the case of the Liverpool Tramways, in the development of which the Deacon system has been retained. Much of the excellence of this system is fairly due to first-rate material and workmanship, to the general design also, and specially to the binding of the rails and sleepers by bolts to the foundation of concrete. The facility for extracting paving sets at the surface when required, without disturbing the neighbouring sets, is also to be noted.

A few medium and minor tramways, also, have retained for new work the system of way on which they were originally executed. With these limited exceptions, new work and renewals are now constructed with girder rails. A great variety of sections of tramway rails are exhibited in the Table, pages 332 and 333, in which upwards of forty rail sections are noted, with the corresponding illustrated sections, Figs. 184 to 205, and 206 to 226 (pages 336, 337). These data, reduced from the section sheets of Messrs. Dick, Kerr & Co., exhibit a remarkable variety, the reason of which is not very obvious, though probably one of the chief causes has arisen from the difficulties of rolling such sections,—prohibitory, for the most part, in the early days of girder rolling,—in large and spread sections. Much of the difficulty has disappeared since steel was introduced to take the place of iron, for the manufacture of girder rails, which it now does entirely; and, in any case, larger and stronger sections have been in demand to meet the heavier work of steam traction.

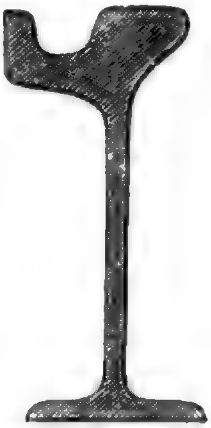


FIG. 183. Girder Rail, by A. Legrand.

TABLE OF WEIGHTS AND LEADING DIMENSIONS OF STEEL TRAM GIRDER RAILS.

(Reduced from the Section Sheets of Messrs. Dick, Kerr & Co.)

Order number.	Names of tramways.	Weight of rail per yard.	Height by width of base.	Width of head over all.	Width of groove.	Minimum thickness of web.	Thickness of base.	
							At edges.	Near web.
No.	Tramways.	Lbs.	Ins. by ins.	Ins.	Ins.	Inch.	Inch.	Inch.
2	Spanish	50 to 53	$4\frac{1}{2} \times 4$	3	1	$\frac{7}{16}$	$\frac{1}{4}$	$\frac{1}{2}$
3	Gateshead-on-Tyne Woolwich and South-east London Wigan Ipswich	56 ,, 58	$5\frac{1}{2} \times 4$	3	1	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{2}$
6	Madrid Bucharest Brighton Malaya Panama	60 ,, 63	5×5	3	1	$\frac{1}{4}$ $\frac{3}{32}$	$\frac{1}{4}$	$\frac{1}{2}$
9	Norwood & Croydon Hartlepool	74 ,, 77	6×6	3	1	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{8}$
10	South Staffordshire Cardiff Southampton La Plata	75 ,, 78	6×6	3	1	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{8}$
11	Accrington Port Glasgow Birmingham Midland	75 ,, 78	6×6	$3\frac{1}{16}$	1	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{8}$
13	Manchester, Bury, and Rochdale	88 ,, 92	6×7	$3\frac{1}{16}$	1	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{5}{8}$
14	Newcastle-on-Tyne	90 ,, 94	7×7	3	1	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{16}$
15	Manchester, Bury, and Rochdale	90 ,, 94	7×7	$3\frac{1}{8}$	1	$\frac{1}{2}$	$\frac{1}{4}$ full.	$\frac{5}{8}$
16	Dublin United	90 ,, 94	7×7	3	$\frac{7}{8}$	$\frac{3}{8}$	$\frac{5}{16}$ bare.	$\frac{5}{8}$
17	Brazilian	35	$3\frac{1}{2} \times 3$	$2\frac{5}{8}$	1	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{8}$
18	Bridgetown	40 ,, 42	$3\frac{1}{2} \times 3$	$2\frac{3}{4}$	1	$\frac{7}{16}$	$\frac{3}{16}$	$\frac{3}{8}$
19	London, Camberwell, and East Dulwich Portsmouth	65 ,, 68	$5\frac{1}{2} \times 5$	$3\frac{1}{16}$	1	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{2}$ bare.
20	Brisbane Seville	55 ,, 57	$4\frac{1}{2} \times 4$	3	1	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{7}{16}$
21	Brisbane	77 ,, 80	$6 \times 6\frac{1}{2}$	3	1	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{7}{16}$

TABLE OF WEIGHTS (*continued*).

Order number.	Names of tramways.	Weight of rail per yard.	Height by width of base.	Width of head over all.	Width of groove.	Minimum thickness of web.	Thickness of base.	
							At edges.	Near web.
No.	Tramways.	Lbs.	Ins. by ins.	Ins.	Ins.	Inch.	Inch.	Inch.
25	Birmingham Leeds Huddersfield Bradford	97 to 100	7 × 7	3¼	7/16	½	5/16 bare.	11/16
26	North London	90 „ 92	6 × 7	3½	1	7/16 full.	5/16	⅝
27	Melbourne	67 „ 70	5½ × 5½	2¾	⅞	⅜	¼	7/8
28	Melbourne	74 „ 77	5 9/16 × 6½	2 13/16	⅞	⅜	¼	½
29	Melbourne	87 „ 90	6 9/16 × 6 5/16	3⅝	⅞	5/16 full.	¼	9/16
30	North Metropolitan South London Edinburgh	90 „ 93	7 1/16 × 6 5/16	3⅜	1	7/16	⅜	11/16
31	Berlin	77 „ 80	6 × 4¼	4¼	1¼	7/16	⅜	7/16
33	Guinness Brewery	76	7¼ × 4	3 9/16	1	7/16	⅜	11/16
34	German	90	7¼ × 7¼	3 1/16	1¼	½	5/16	11/16
35	German	82	6 × 5¼	3¼	1¼	⅜	⅝	11/16
36	Argentine	103	6½ × 6 9/16	3½	¾	⅜	5/16	11/16
37	Guinness Brewery	79	7¼ × 4	3¼	1½	⅜	¼	11/16
38	Argentine	84	6 × 7	3	⅞	7/16	5/16	½
39	Argentine	102	6 × 7	3¼	⅞	9/16	5/16	9/16
40	Argentine	74	5½ × 6¼	3¼	1 7/16	13/32	11/32	9/16
41	Midland	76	6 × 6	2¾	1⅛	⅜	¼	⅜
42	South London	101	8 × 6	3 5/16	1 1/16	½	⅜	9/16
43	Argentine	106	6½ × 7	3¼	1 1/16	15/32	5/16	11/16
44	Argentine	85	6 × 4½	3½	1¼	½	⅜	½
45	Argentine	72	5½ × 5¼	3 9/16	1½	⅜	¼	9/16
46	Hamburg Barcelona	86	5¾ × 5½	4¾	1¼	⅜	5/16	9/16
47	London	90	7 × 6½	3¼	1	7/16	5/16	9/16
48	Spanish	48	4 × 4½	3 1/16	1⅛	⅜	7/16	7/16
49	Mexican	41	6 × 4	2½	1	¼	5/16	⅜ bare.
50	Glasgow	79	6½ × 5½	3½	1½	7/16	¼	⅜
51	Indian	95	7 × 6½	3¼	1 1/16	7/16	5/16	⅜
54	Alford and Sutton	46	4⅝ × 3 5/16	3¼	1⅛	⅜	¼ bare.	7/16
55	German	83	7½ × 5½	3¾	1	⅜	5/16	7/16

Reverting to the Table, it appears that steel girder rails have been rolled, weighing from 50 lbs. per yard to 106 lbs. per yard ;

that girder rails vary in height from 4 inches to a maximum of 8 inches; and from a 3-inch width of base flange to a maximum width of 7 inches, and that the head varies from 2⅝ inches to 4¼ inches in width.

The flange base tapers transversely in thickness from about ¼ inch in thickness, near the edge, to from ⅝ inch to 11/16 inch, speaking generally, near the web: the base joining the web with a quarter circle filling. The web is most commonly from ⅜ inch to ½ inch in thickness. In several instances the thickness of the web is excessive, as in No. 36 and others. Nos. 1, 14, 15, 16, and 30 are fairly well-balanced sections, without undue fulness of web; and having the vertical centre line of the web just in line, or very nearly so, with the edge of the groove, through which the vertical pressure of the load passes. No. 28 gives an instance of a bad side-bearing for the fish-plates, under the tread. It is much too oblique for stability, and would have been much better if it had been more steeply sloped, with a suitable fish-plate, as indicated in dot lining. Nos. 6, 47, and 55 offer good bearing surface for fish-plates. In No. 35, the overhang of the principal bearing point of the tread is specifically bad, resulting in severe torsional stress.

The lip flange or guard, forming the outer side of the groove, should be about ½ inch in thickness.

The usual tests for steel tramway girder rails are as follows:—

Breaking stress, tensile, from 37 tons to 43 tons per square inch; elongation in a length of 8 inches, at least 15 per cent.; contraction of sectional area, at least 30 per cent. A short piece of the rail, 5 feet long, placed on supports 3 feet apart, must resist a blow from a weight of 1 ton falling freely on its centre or middle point, from a given height, without causing more than 1 inch of deflection at the centre, according to the following scale:—

Weight of rail per yard.	Height of first fall.	Height of second fall.
60 lbs. to 70 lbs.	6 feet.	15 feet.
70 ,, 80 ,,	7 ,,	17½ ,,
80 ,, 90 ,,	8 ,,	20 ,,
90 ,, 100 ,,	9 ,,	22½ ,,

The same piece of rail, after having been so tested, must, in the same position, be exposed to a second blow from the same weight falling freely through the heights above noted for the second fall, without exhibiting any sign of fracture.

The girder rails for the Huddersfield Corporation Tramways were tested both for deflection under a falling weight, and also for deflection under a given dead pressure. A piece of the Huddersfield rail, of 98 lbs. per yard, 5 feet long, was laid on supports $3\frac{1}{2}$ feet apart; and was exposed to four successive blows from a falling weight of half a ton, or 1,120 lbs., dropped through a height of 20 feet.

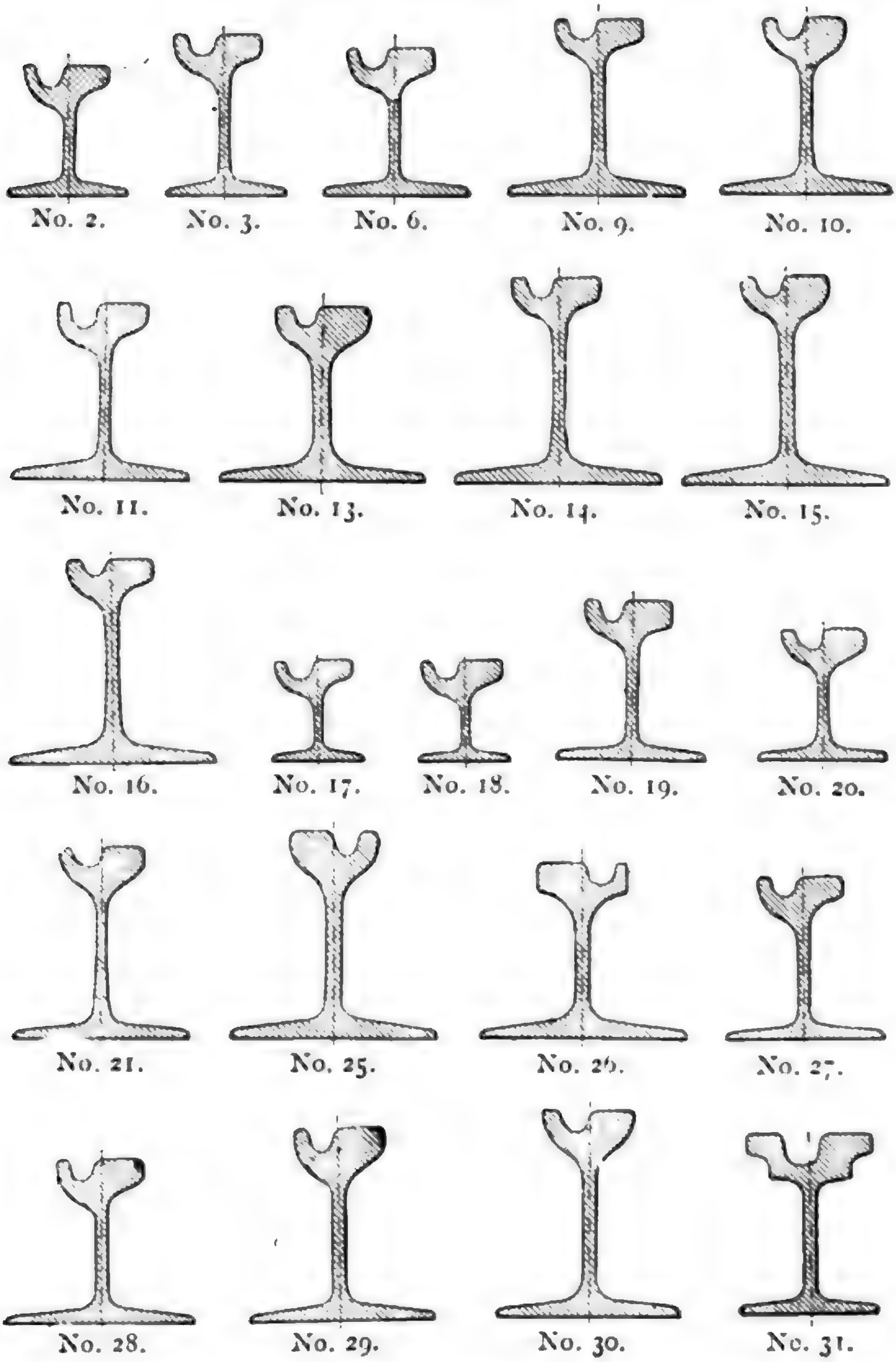
1st blow	$\frac{15}{16}$	inch deflection	at middle
2nd ,,	$1\frac{13}{16}$	,,	,,
3rd ,,	$2\frac{5}{8}$	,,	,,
4th ,,	$3\frac{1}{2}$	,,	,,

A dead pressure of 25 tons was applied at the middle of a like piece of rail for a period of thirty minutes. The load was then removed, and it was found that there was no permanent set.

Samples of girder rails supplied by Messrs. Dick, Kerr & Co. to several tramway companies were tested for tensile resistance. Particulars, with sections of the rails, are given in the Table, pages 332 and 333, and illustrations, Figs. 184 to 205, and 206 to 226 (pages 336, 337). They can be identified by means of the reference order numbers.

RESULTS OF TESTS OF TRAMWAY GIRDER RAILS FOR TENSILE RESISTANCE.

Tramway.	Order no. of section.	Weight of rail per yard.	Breaking weight (tensile) per sq. inch.	Elongation in a length of eighteen inches.	Contraction of sectional area.
	No.	Lbs.	Tons.	Per cent.	Per cent.
West Metropolitan .	10	76	42·13	24·90	52·64
Durban . . .	6	50	41·55	23·00	53·18
Calcutta . . .	51	95	44·76	19·25	52·40
North Metropolitan .	30	90	42·00	21·00	55·60
Huddersfield . .	25	98	43·81	18·10	47·80
London . . .	47	90	39·61	20·40	58·88
Brazilian . . .	17	37	39·28	20·50	51·95
Averages . . .	..	..	41·87	21·02	53·20



No. 2. No. 3. No. 6. No. 9. No. 10.

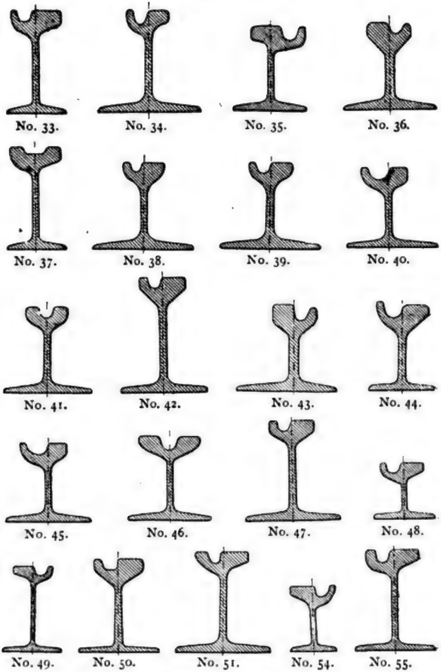
No. 11. No. 13. No. 14. No. 15.

No. 16. No. 17. No. 18. No. 19. No. 20.

No. 21. No. 25. No. 26. No. 27.

No. 28. No. 29. No. 30. No. 31.

FIGS. 184 to 205.—Sections of Steel Girder Rails. (Reduced from the Section Sheets of Messrs. Dick, Kerr & Co.) Scale $\frac{1}{8}$.



No. 33. No. 34. No. 35. No. 36.

No. 37. No. 38. No. 39. No. 40.

No. 41. No. 42. No. 43. No. 44.

No. 45. No. 46. No. 47. No. 48.

No. 49. No. 50. No. 51. No. 54. No. 55.

FIGS. 206 to 226.—Sections of Steel Girder Rails. (Reduced from the Section Sheets of Messrs. Dick, Kerr & Co.) Scale $\frac{1}{8}$.

A type of girder-rail tramway recently designed and constructed by Mr. Joseph Kincaid, is illustrated by Figs. 227 and 228. The rails are of steel, weighing 78 lbs. per yard; 6 inches high, 6 inches wide at the sole or base. The web is ⅝ inch thick; the base is ½ inch thick near the web; tapering in section to 5/16 inch at the edges. The head is 3 inches in total width, giving 1½ inches width of tread, 1 inch width of groove, and ½ inch width or thickness of guard-flange or fillet. The rails are fished with ⅝-inch iron plates, 14 inches long, and four ¾-inch bolts and nuts. The joints are further secured with ⅜-inch iron joint-plates, or slipper-plates, 16 inches long, 9 inches wide, turned over the edges of the base, to give a tight hold of the ends of the rails without the aid of bolts.

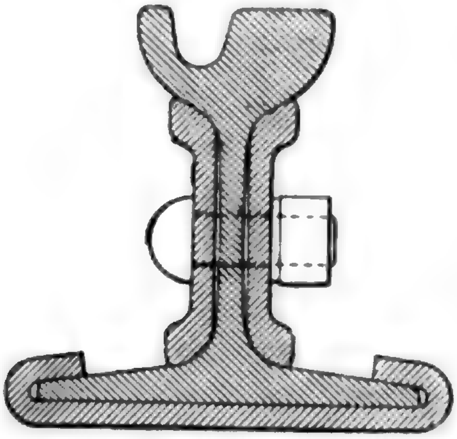


FIG. 227.—Type of Girder Rail Tramway (Mr. Kincaid):—Section of Rails and Fastenings. Scale ¼.

The ground is excavated for a depth of 12 inches below the level of the rails, and upon the bottom of the excavation a 6-inch bed of Portland-cement concrete is laid in. The rails are laid on the concrete, and a 1-inch layer of gravel covers the concrete, to receive and give bedding for the pavement, which consists of 5-inch granite sets. The rails are tied to the usual gauge, 4 feet 8½ inches, by iron tie-bars, 1½ inches by ⅜ inch, 8 feet apart, notched at one end into the web of the rail, and set to gauge by

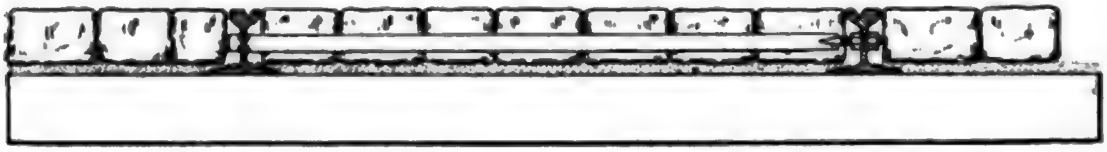


FIG. 228.—Type of Girder Rail Tramway (Mr. Kincaid):—Cross Section of Way. Scale 1/24.

means of a screw formed on the other end, with a nut and a jamb-nut. The interspaces between the sides of the rails and the paving sets are packed with concrete.

A statement of quantities and costs for one mile of single line laid with girder rails, in accordance with the design as illustrated and described, is here subjoined.

TYPE GIRDER RAIL TRAMWAY: QUANTITIES AND COST OF ONE MILE, SINGLE LINE, 1893.

(Mr. Kincaid).

Tons.	cwts.	qrs.		£	s.	d.	£	s.	d.
122	11	2	Steel girder rails, 78 lbs. per yard	6	0	0—	735	9	0
3	4	3	Wrought-iron fish-plates, 16½ lbs. per pair	7	0	0—	22	13	3
2	1	1	Wrought-iron joint plates, 10½ lbs. each	12	0	0—	24	15	0
4	10	0	Wrought-iron tie-bars, 15¼ lbs. each	12	0	0—	54	0	0
1	0	0	Bolts, nuts, and washers	20	0	0—	20	0	0
1,662	c. yds.		Excavation	0	2	6—	207	15	0
846	„		Portland cement concrete	0	15	0—	634	10	0
1,760	l. yds.		Laying the way	0	1	6—	132	0	0
			Total cost of way per mile, single line				£1,831	2	3
4,376	s. yds.		Granite paving sets, including 1-inch bed of gravel, laying and grouting per mile, single line	0	7	6—	1641	0	0
			Total cost of way and paving per mile, single line				£3,472	2	3

Say £3,500.

CHAPTER XXVIII.

GENERAL CONCLUSIONS ON THE CONSTRUCTION OF TRAMWAYS.

IT needs but a glance at the illustrations of practice in tramway construction, to perceive that great advances have been made in design and execution. The advantages of solidity and directness of construction have been developed in the experience of the Liverpool Corporation Tramways, where the steel rail, longitudinal timber sleeper, and concrete bed, having been thoroughly united, in conjunction with a perfect system of paving, have, during the last three or four years, endured the heaviest cross traffic and longitudinal traffic in the world, at but a nominal cost for repair. The adoption of cast-iron sleepers for these tramways led up to one of the most complete systems of tramway for streets of maximum heavy traffic.

The system of Barker and the more recent systems of Shaw, Mackieson, and Dugdale, may be classed with the Deacon system (Liverpool), as structural combinations of rails and continuous, or nearly continuous, cast-iron longitudinal sleepers. But whilst in Barker's and Deacon's systems solid vertical walls are presented as lateral bearing surfaces for the paving, in the others the sleepers are of the nature of open framing, and are packed flush with concrete to provide lateral bearing surface. With the exception of the Shaw system, in which the rail is supported on pedestals at short intervals, they make a floor for supporting the rails, which affords a bearing that is practically continuous.

The girder-rail and cross-sleeper system, embedded in concrete, now practised in Glasgow, is an instance of perfected design, logically developed by experience. In the retention of the cross-timber sleeper, with respect to which the engineers of the Glasgow Corporation Tramways stand almost alone in their practice, there is no evil consequence whatever, and there are the advantages of complete control of gauge, economy of maintenance, partial absorption of vibration, efficient support where underground subsidences may happen to take place, and the facility for shifting the rails laterally upon the sleepers without disturbance of the substructure, where such adjustment may happen to be required.

The Kincaid system, likewise, has been logically matured, and it is a satisfactory development of the type of rail supported on isolated pedestals. It was improved by the adoption of rails of a better and stronger section, by the extension of the bases of the chairs or sleepers, so as to form a practically continuous base, by the adoption of iron cotter-fastenings, and by the development of a sufficient foundation of concrete. The supporting of the rails at intervals only, provides for a slight elastic reaction, and the consequent prevention of absolute rigidity, whilst the vertical stress is, by the method of construction, landed on and limited to the centre of the pedestal-sleeper,—a concentration which is conducive to stability, and is desirable in a system in which transverse cotter-fastenings are adopted.

The principle of a system of rails supported by comparatively isolated chairs of cast-iron, is embodied in the systems of Wilson, Vignoles, and Aldred-Spielmann.

In the Wilson system, laid on the Southampton Street Tramways, a rail of considerable section is carried in cast-iron chairs of large base, at wide intervals, without any approach to continuity. The rail is unusually heavy, of its kind—55 lbs. per yard;—and it has an unusually long bearing in the chairs: conditions ensuring a great degree of strength, and contrasting in this respect favourably with those of the Kincaid way at Bristol, in which the chairs, at the same distance apart, and of great length of base, only give a 3½-inch bearing to the rail, which weighs just 50 lbs. to the yard.

The Vignoles rail is carried in chairs at 30-inch centres, and is correspondingly light—42½ lbs. per yard,—lighter than any other suspended rail. But the most has been made of the metal, by rolling the rail to a depth of 5 inches, though the central web is but ⅜ inch in thickness. The rail is open to the objection of having only a one-sided support, on a half-chair, as it may be called, to which, necessarily, it is bolted laterally: the rail depending upon the bolts and nuts to be kept in position. This dependence is rendered inevitable by the inclination of the bearing surface of the rail upon the top of the chair. Had the inclination been reverse, the stability of the structure would have been greater. The employment of transverse timber sleepers is a good feature in the design of this system.

The Aldred-Spielmann rail, laid in cast-iron chairs on cross sleepers, is interesting as a reversible rail, and as a rail which fishes itself, by the break-joint method of laying the two halves of the rail. Since the bearing rail is, in a manner, wedged upon the guard-rail, constant contact and tightness, as well as mutual support, are ensured. As the way is laid on and spiked to transverse timber sleepers in concrete, it is both a secure and an easy rail; and it has done good service in the London Tramways and other lines.

Page's system of semi-continuous bearings of rails and wrought-iron standards may be classed with the Kincaid and Cockburn-Muir systems. It is open to the objection that the width of the bearing for the rail upon the sleeper is very narrow, and that the rail considerably overhangs its own base, at both sides. In the other systems, the rail takes a bearing for its whole breadth on the sleeper or chair. In Meakins' system, as laid by Mr. Dixon, the rail is also supported on a bearing which is narrower than its own width. But the objection of overhang, in this system, is obviated by the secure method of uniting the rail with the angle-iron brackets, by riveting.

Ways constructed on the principle of the girder-rail are amply represented by the systems of Gowans, Macrae, Johnstones & Rankine, Winby & Levick, and Kerr. To Mr. Gowans is due the merit of having first promoted and introduced the girder-rail, which Mr. Macrae was the first to lay down. The rail, as devised by Mr. Gowans, was peculiarly formed,—with a flange-base wider on one side of the web than on the other; and with perforations in the rail. These refinements have not, generally, been much appreciated. Mr. Macrae abandoned them, though he apprehended the advantages of the girder form; and he adopted an ordinary solid rail, corresponding to the old railway rail of Vignoles. So also have the other engineers just named. Difficulties naturally arose in the perfecting of the methods of rolling rails—particularly steel rails—with a groove, and with so wide a base; though a wide base was only needful where the rail was to be embedded in concrete and was to rely on its hold upon this alone for stability. It was preferable, as a matter of manufacture, that a base-flange of limited width should be rolled; and a limited flange was adopted by Messrs. Johnstones & Rankine, who really did not require a wide base, since they possessed a solid foundation in the transverse sleepers which they employ, to which the rails could be securely spiked. Messrs. Winby & Levick and Mr. Kerr devised other means of utilising the limited base-flange, by bolting and clipping the girder rail to wider base-plates or sleepers, and so providing ample bearing surface in combination with the limited flange-base.

In the later developments of the solid girder-rail, conveniently rolled sections have been introduced. Messrs. Johnstones & Rankine's system obviously combines the advantage of a well-constructed foundation and a secure hold for the rails, with perfect freedom for detachment or uplifting when removal is required; whilst Mr. Kerr anchors his rails and sleepers together in the concrete—inseparable without breaking up the foundation; and Messrs. Winby & Levick, on the contrary, content themselves, like Mr. Barker, with depositing the metal structure on the floor of the excavated space, reserving the freedom for readily detaching and removing the rails.

With regard to the sections of rails for what may be called the composite ways, in which rails are laid on metal sleepers or chairs, they have evidently drifted towards the T section—a grooved head with a central web—initiated by Mr. Cockburn-Muir. Its advantages are manifest. In it are combined lightness, strength, stiffness, and compactness; and facility for fish-jointing when required, though it must be acknowledged that the joint made by Mr. Cockburn-Muir, by means of a long wedge in his block-sleeper, has never been surpassed. Fastenings by means of wedges or bolts are generally preferable to cotter fastenings.

As to the material for tram-rails, the results of the respective wears of steel rails and iron rails in Glasgow, reported by Messrs. Johnstones & Rankine, appear to show that the iron rails were as durable as the steel rails; whilst it is also apparent, from the results of Mr. Cockburn-Muir's tests for deflection, that iron rails were, within their elastic limits, practically as stiff as steel rails.

The imperative necessity for maintaining the pavement coincidently with the way, not only for the special business of the tramway, but also for the other business of the street, has led to the general adoption of means for efficiently supporting the pavement, particularly the parts adjacent to such as lies next the rails; and, in addition, at Liverpool, the exact dressing of the paving-stones, next the rails, in order to provide the maximum area of bearing surface and so to minimise the wear, and the consequent tendency to form objectionable ridges next the rails. The reports of the London General Omnibus Company afford evidence of the inconvenience of unequal and local wear of way and paving. "The deplorable state of the main thoroughfares in the eastern, southern, and northern parts of the Metropolis," it was reported in 1878, "was destructive of the wheels, springs, and under carriages of ordinary vehicles. The cost for wheels alone for the Company's omnibuses increased from £9 10s. per omnibus per year to £15 per omnibus per year since the introduction of tramways. Valuable horses have constantly been injured by straining and slipping on the rails."

It is apparent that a first-rate rolling surface is of the essence of a tramway—a street railway;—and it is not well to study too closely the mere element of first cost, in the amount of which, for efficient systems of tramway, the variation is not of very considerable importance. The practical value of a good rolling-surface, on the contrary, can scarcely be over-estimated; for the running and car expenses are influenced to a very great extent by the condition of the surface, and they constitute nearly two-thirds of the total working expenses.

With a perfect rolling surface, an even and durable pavement must be associated, in order that uniform levels may be preserved, not necessarily for the special business of the tramway only, but also for the other business of the street. A completely constructed tramway must, therefore, combine a perfect unyielding rolling surface with a firm and durable pavement. A perfect rolling surface it was impossible to fulfil so long as the rails were fastened by vertical spikes or bolts passed through the groove in the rail. But when the side-fastenings of Mr. Larsen, improved by Mr. Hopkins, were introduced, by which the rail was lapped upon the longitudinal sleeper, and was tied down by lateral staples at each side, entirely out of the reach of derangement by the strokes of the traffic, the problem was greatly simplified. The stiffness of the rail, vertically as well as laterally, was greatly augmented by the adoption of the side-fastenings. These, whilst they were placed beyond the reach of blows at the surface, were enabled, in virtue of their lateral disposition, to resist with powerful leverage the force of oblique lateral strokes—a function in respect of which a central spike or bolt was clearly inferior to the side-staple. Vertical movement under the traffic was prevented, and the destructive action of blows from the surface was checked in the initiatory stage. The staple-fastening was so simple, and, after its introduction, so obvious, that one may wonder at the primitive combination of a flat-grooved bar, of minimum strength, with a vertical spike, which was used for several years. Let us wonder, and pass on. But before passing on, let us note that Mr. Livesey and Mr. Cockburn-Muir had from an early period perfectly well appreciated the mechanical necessity for applying the fastenings of the rail apart from the rolling surface, and had accordingly applied wedge-fastenings at the sides of the rail. Their system, as systems of iron way, were long in advance of their time in the home countries; and though these systems have not entered into the domain of English practice, they were long since in general practice abroad.

The function of the substructure is to support the rails, and also to keep them in gauge, whilst the foundation is laid to provide a firm and uniform base for the rails and the paving conjointly, maintaining both of them to one level. In some systems of tramway, the substructure is to some extent identified with, and forms part of, the foundation. The foundation, in nearly all systems, consists wholly or mainly of concrete—an artificial stone or compound of considerable cohesive force, admirably adapted, when properly made, for supporting dead weights on the ground, and distributing superincumbent pressure. With a broad base of concrete the maintenance of the rails and the pavement at a uniform level may be effectually performed. A wide solid base is indispensable for the purpose, and if not already provided by nature or by previous use, it must be supplied by art.

The substructure should afford a continuous support to the rail, for the construction of a continuous bearing is simpler and better than the construction required for intermittent bearings; and, before all, the continuity of support contributes to the perfection and permanence of the rolling surface, not alone by insuring longitudinal and lateral stiffness, but also by preventing the twisting or torsion of the rail which would be caused by the eccentric pressure of the wheel on a suspended rail. Take the centre-line of the 2-inch rolling-surface of a rail 4 inches wide, as the line of insistent vertical pressure; it lies only one inch from the outer edge of the rail, and it is one inch off the central line of support. Obviously, therefore, the rail which is supported by intermittent bearings, is exposed to twisting stress between the bearings, tending to cant it sidewise; and it is required to be stiffened enough to resist such torsional stress. Besides, the same stress ultimately reaches and strains the fastenings.

An extensive area of bearing-surface between the rails, the substructure, and the foundation is not indispensable. It has been demonstrated by experience that the continuous bearing of two longitudinal sleepers, 4 inches wide, on sound concrete, is sufficient for sustaining the heaviest traffic of the streets, and maintaining the level of the rails. Two widths of 4 inches each, or 8 inches together, provide two square feet of bearing surface per lineal yard of way. This datum has been arrived at, rather than deduced, from practical results, simply because the first English rails for tramways were 4 inches in width, and the longitudinal sleepers upon which they were placed were made of the same width, in order that the granite pavement might be set close up to the rail at both sides. A less proportion of bearing surface, fairly placed, would suffice. In fact, Mr. Deacon's rail and longitudinal sleeper are only 3¼ inches in width—a width which affords an area of bearing surface of not more than 1⅝ square foot per lineal yard for two sleepers. Mr. Kincaid's intermittent supports on concrete present an area of 2⅓ square feet of bearing per lineal yard. It might be difficult to prescribe the safe limit of area of bearing on concrete, for Portland-cement concrete, twelve months old, has been proved by Mr. Grant to be capable, before being crushed, of resisting loads of from 91 tons to 170 tons per square foot, according to the strength of the composition.

The mere extent of the area of bearing-surface on a foundation of concrete, therefore, is practically of no moment, and does not in itself affect, one way or another, the character of the way for durability or efficiency—supposing, be it remembered, that the concrete is faithfully made and laid; and no other supposition, it has been proved by experience, should ever be entertained.

It is scarcely necessary to add that longitudinal sleepers of timber, in good condition, are quite capable, without suffering undue compression, of permanently supporting rails of a width of 3 or 4 inches, having a continuous bearing on the sleepers.

But the rails must also be maintained to gauge by the substructure. In other words, the rails must be prevented from spreading apart, and so widening the gauge or distance between them. The maintenance of gauge is indispensable, for, if the gauge be strained, the flanges of car-wheels, which are devised so as to run near the inner sides of the grooves, when fairly placed, bind against the ledges which form the inner slopes of the grooves. The effect of such a spreading is greatly to augment the frictional resistance of the cars, and, if continued far enough, to grind away the flanges and reduce their thickness, to increase the difficulty of passing the points and crossings, and, finally, to lead to the derailment of the cars. Fortunately, the derailment of a tramcar, though it may prove of great inconvenience, is a trivial matter compared with the derailment of a railway train; but the other evils of a spread of gauge are of much greater magnitude on a tramway than their analogues on a railway. It need scarcely be added that when railway-carriages, wagons, or locomotives are passed over tramways, the means of maintaining the gauge must be positive and precise. The pavement by which the rails are enclosed affords, no doubt, material assistance in keeping them to gauge; but it can be accepted only as an auxiliary.

The method of binding the rails to gauge by transverse sleepers, to which longitudinal sleepers are fixed, by the medium of solid chairs or of brackets, or by notching together, is positive. So, also, is the method of tie-bars connecting the sleepers which carry the rails. When longitudinal sleepers are bedded in concrete for a portion of their height, the concrete forms a connection which may be said to be positive; but in practice it is treated only as auxiliary to other connections. Mr. Kincaid's chairs were solidly embedded in blocks of concrete, which were constructed in holes formed in the ground. Nevertheless, in macadamised roads, where no paving was provided, Mr. Kincaid applied a cross tie-rod to each pair of joint-chairs; and in Sheffield a solid bed of concrete was laid for the whole width, in substitution for the isolated blocks.

Transverse sleepers of wood give great satisfaction. Transverse sleepers of wrought iron, like Vauteren's, used on Continental railways, might do well; but the wood sleeper is the better, for it possesses bulk and surface, to make and keep a place for itself, and to adhere by friction to the surrounding concrete.

That a tramway should be cushioned on an elastic substance—

wood—is a doctrine which has been maintained with some degree of persistency. That it should be grounded on a hard substructure—cast iron—is a doctrine maintained by others. The question of the elasticity of the material of the substructure—elasticity in the conventional sense—is a matter of perfect indifference. Wood is elastic, so also is cast iron. The action is rolling, not percussive; the speed is low, not high; and the cars, as well as the engines of the future, are, and will be, placed on springs having a wide elastic range. The pavement of streets—granite stones bedded on sand—is not, conventionally, elastic; yet it answers well for the passage of loads at the customary speed of street traffic. Elastic pavements have been tried, and they have failed. The truth is that the depth of structure necessary for the formation of a tramway is sufficient for inducing as much elasticity—perceptible to the touch, if not to the eye—as is needful to prevent a sound structure from shaking itself loose.

The form of section of the groove in the rail is a subject deserving of careful consideration. In many of the examples of rails which have been illustrated, it may be noted that the sides of the groove are formed with a greater degree of splay inwards than outwards, *from* the wheel than under the wheel. The motive for the greater splay has been, in some instances, to economise metal; but the economy thus effected is simply insignificant. By other designers a low slope has been adopted, with a view to the more facile extrusion of dried mud and other detritus from the groove by the wedging action of the passing wheel-flanges, than is likely to take place when the sides are vertical. There is incurred a much greater resistance to traction when the groove is occupied by hard deposit than when it is clear; since it is inevitable that the mud and small stones or gravel, which find a lodgment in the groove, must be either expelled or trodden upon by the flanges of the wheels. It is a matter of common observation that the resistance is much increased under such conditions, and the principal reason is not far to seek: the wheels run at the same time upon two circumferences of different radii—those of the tread and the flange. Now, a square groove, by its form, resists the expulsion of detritus; and it may happen, and does frequently happen, that the resistance of the car over choked-up grooves is so much increased, that it amounts to as much as that of wheels running on common roads. In the sections of the American grooved-rails, and particularly Mr. Light's section, it is obvious that the advantage of a widely sloping berme was appreciated by the designers of those sections. The motive of the extremely contracted grooves which have been practised—some of them not exceeding an inch in width—and which, when clear, provided little more than clearance for wheel-flanges, is the fear of the entanglement of the narrow-tyred wheels of cabs and carriages in the grooves. But it is known that the derangement of common road vehicles is almost wholly caused by the girding of their wheels against the outer sides of the rails, when the surface of the pavement is permitted to sink below the proper level—a cause of disorder with which the groove is not concerned.

It is further to be noted that, by the occasional grounding of the wheel-flanges over the bottom of the groove, by the intervention of mud, dust, or stones, the metal at that, the weakest point, is heavily stressed. The flanges may also ground directly on the bottom, where the tread of the rail is reduced in height by wear, when a like effect may be produced. It is found that old thin rails subject to such action are spread laterally, and are occasionally split through the bottom of the groove.

The form of the groove, then, is a point of importance, and the best form is that in which the side next the rolling surface is vertical, and the whole of the slope is given to the inner side.

The pavement should be specifically adapted to the tramway, and the chief concern is to construct it so that it shall maintain its level, and remain flush with the rails. A great deal of precaution has been taken for preventing the rails from sinking; whilst the pavement has been laid without sufficient permanent support. A pavement that may suffice for a street untrammelled by rails, laid on loose sand, gravel, or ashes, is not sufficient to match a pair of rigidly supported rails, carried on an unyielding foundation. There is nothing better to be done, for matching the ordinary wall-sided rail, than to bring up a solid unyielding foundation for the paving, identical with the foundation for the rails. This necessary object is fulfilled by the concreting of the subspace up to the level of the under side of the paving stones, as a bottom upon which they may, with the aid of a thin layer of sand, stand to the level. Finally, as a security that neither will water penetrate, nor sand nor mud work up, the paving sets should be grouted with an adhesive, elastic, bituminous mixture.

Adopting the conclusions just announced as standards for estimating the merits of different systems of tramway, it would appear that, upon the whole, the recently-made tramways of Glasgow afford the best example of tramway having a timber substructure hitherto actually constructed in its entirety.

Of the tramways having substructures of iron the system of Mr. Kincaid is the only one of which successful experience has been acquired in England. The isolated chairs or stools at 3-feet centres are each levelled and set independently. In this respect, Mr. Livesey's system of coupled stools—two stools on one longitudinal sleeper—is better; for they make a structural connection, and they can be levelled and set with facility. They are, in addition, efficiently tied transversely by two tie-bars, and thus the stools and sleepers are framed together both longitudinally and transversely, and assist each other in a manner which is not available on Mr. Kincaid's system of independent chairs. These are not connected together either longitudinally or transversely, and depend for their stability each on the fixity of its own portion of concrete.

The length of the bearings of the rail on the intermediate sleepers of Mr. Kincaid and of Mr. Livesey is 3½ inches; whilst that of Mr. Cockburn-Muir is 11½ inches. It is clear enough that the long bearing on the sleeper of the last-named engineer must beneficially stiffen the rail, and he has taken advantage of such aid in adopting a longer distance apart for the sleepers, and employing a rail of less weight than those of the other engineers. The three systems may be thus brought into comparison:—

Rails.		Weight per yard.	Centres of sleepers.		Span between bearings.
		lbs.	Feet.	Inches.	Inches.
Mr. Kincaid . .	iron	43	3	0	32½
Mr. Livesey . .	steel	40	3	0	30½
Mr. Cockburn-Muir .	iron	30	3	6	30½

Now, it is to be premised that a rail may be strong enough, as a beam, to support any load that may be placed upon it, whilst it may not be stiff enough: for, resistance to deflection must be the ruling consideration in the design of a tramway. Deflection should be reduced to a minimum, since vertical stiffness is the first condition for insuring a minimum tractional resistance. It is obvious, too, that vertical stiffness is an essential condition for insuring the stability of the fastenings and of the paving.

The stiffness of a rail is inversely as the cube of the length, and Mr. Cockburn-Muir's rail, if it had had the same section as Mr. Kincaid's, would have been stiffer in the ratio of $32{\cdot}5^3$ to $30{\cdot}5^3$, or of 3433 to 2837, or nearly 5 to 4. That a difference of 2 inches in the span should cause a difference of a fourth or a fifth in the stiffness of a rail supported on bearings at intervals, is a noteworthy fact, and it points to the advantage of compactness of span for intermittent bearings, and of the reduction of the overhang of the rail by giving to it a considerable length of bearing surface upon the chair or stool. These advantages may be exemplified by supposing Mr. Cockburn-Muir's block-sleepers to be placed apart at 3-feet centres, the same distance apart as Mr. Kincaid's sleepers. The spans between the bearings and the relative stiffnesses of the rails—inversely as the cubes of the spans—supposing that the same rail is laid in both cases, would be as follows:—

	Centres of sleepers.	Spans between bearings.	Relative stiffness.
Short bearing . . .	3 feet	32½ inches, as	1
Long bearing . . .	3 feet	24½ inches, as	2⅓

Showing that if Mr. Kincaid's rail were laid on chairs with

11½-inch bearing surfaces, it would possess 2¼ times the stiffness; or, otherwise, the deflection of the rail between the longer bearings would be less than half of what it amounts to between the actual bearings, of shorter length. The form of Mr. Kincaid's chairs, it may be observed, lends itself readily to the extension of the bearing surface; and even if the 3½-inch bearing surface of the intermediate chairs were only doubled in length, making a 7-inch bearing, uniform with the bearing at the joint-chairs, the stiffness would be increased by nearly one-half.

It is logically deducible by the same line of argument, that with a continuous bearing under the rail, the stiffness is indefinitely greater than it can be upon bearings at intervals. But it is not to be concluded that the rail on a continuous bearing may be made indefinitely light in scantling. The rail must be of sufficient scantling to enable it to resist the wire-drawing and out-rolling action of moving loads concentrated under the wheels; to check the effects of occasional weakness of substructure; to bridge over the inevitable junctions of the substructure, even when it is nominally continuous, and to resist, also, accidental derangements of the way, and the numberless varieties of irregular stress to which tram-rails are subject.

These conditions are fulfilled by the solid girder-rail, now universally employed. In this rail the functions of the top, the middle, and the bottom are united in one piece,—combining simplicity, strength, stiffness, solidity, and durability. Thus it appears that, constructionally, tramways advanced in a circle. They began with one piece, and they have ended in one piece.

PART IV.

TRAMWAY CARS.

CHAPTER I.

HISTORICAL NOTICE OF TRAMWAY CARS.

THE earliest cars specially designed for the modern tramway were constructed, in 1831, for the New York and Haarlem Street Railway, of which the first section, in the city of New York, was opened in 1832. These cars, illustrated in Fig. 229, were constructed with bodies like those of the road coaches of the time. The car had three compartments, each of which had side doors. The body was supported on leather springs. The driver was seated on a dickey, or elevated seat, at the front; the brake, which acted on one pair of wheels only, was moved by the driver's foot. The wheels, brakes, drawheads, &c.,

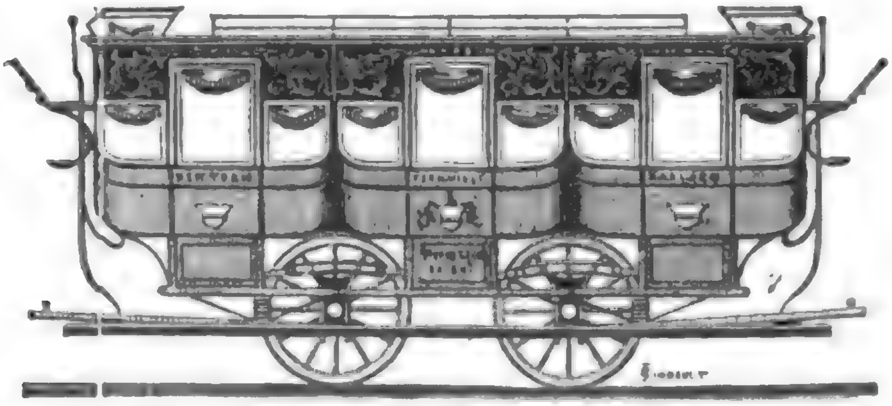


FIG. 229. Original Tramcar, manufactured in 1831, by Mr. John Stephenson, New York.

were combined in a "carriage-part," a structure independent of the body, which rested on the four axle-boxes of the carriage-part. On this principle of arrangement, tramway cars were for several years constructed, until it was found by experience that the portions of the carriage-part not carried by the springs, soon became worn and disordered, and required to be early renewed. One of the first alterations in design consisted of the substitution of laminated steel springs for the leather springs; the ends of the springs were confined in pockets on the under side of the body, whilst the springs were secured, by the middle, to the axle-box. Then the carriage-part was dispensed with. Pedestals in jaw-plates, known as axle-guards in England, were not used. Though this form of running gear was practised for several years, it was unsatisfactory, because the adjustment of wheels and axles was not positive. Single jaw-plates were then applied to take the axle-boxes and keep the axles square.

About the year 1856, volute steel springs were substituted for laminated side-springs, and were succeeded by "spiral," or, properly, helical steel springs. In every case, a single steel spring rested on the top of the axle-box. But, in 1858, a pair of helical springs were provided for each bearing; a yoke was placed on the axle-box, astride, and sustained a spring at each side of the box. About the same time, a method of preparing india-rubber was discovered, by which it preserved its elasticity independently of heat and cold, whilst its power of sustaining loads was greatly increased. The combination of cheapness, durability, and smoothness of action, led to the abandonment of steel bearing springs for those of india-rubber. But, since the expiration of the patent for the method of preparation, the manufacture of the india-rubber springs was thrown open to the public, inferior goods were placed in the market, the good name acquired for india-rubber springs was damaged, and, as a consequence, helical and other springs came again into demand.

The wheels made for the original American car, Fig. 229, were of cast iron, with flat spokes, as shown. The "hub," or nave, was parted radially into three sections, to provide for the shrinking of the metal as it cooled. But the wheel was not strong, and solid wood wheels with iron tyres were substituted. These were heavy and expensive, and they were liable to fail by the loosening of the tyre. About 1834, the cast-iron plate-wheel, or disc-wheel, was introduced; it is regarded in America as the best type of wheel for all kinds of service.

It was for many years supposed that a tramcar would not stay on the track if the depth of the flanges of the wheels were less than 1¼ inches; and, although a slight reduction was made on the depth, it was not until the year 1857 that it was discovered that a depth of half an inch was sufficient for the purpose. The half-inch flange is now universally employed on tramways.

The brakes, until 1858, consisted of clogs or shoes applied to the treads of the wheels; but when the flat tram-rail, or step-rail, came into use, it was found that, as good car-wheels wear off ½ inch of the thickness at the circumference before being "used up," the flange became half an inch deeper, and was made to "touch bottom," when, usually at the end of three or four years, the rail was split by the penetrating action of the flange. The additional rubbing resistance, at the same time, arising from the frictional contact of the two surfaces of different radii—the tread and the flange—amounted to from 30 to 50 per cent. of the resistance under normal conditions. But the objections of unequal wear were met by extending the width of the brake-blocks, so as to confine and take a bearing upon the flange as well as upon the tread of the wheel. The flange was worn down at the same rate as the tread, the life of the wheel was prolonged, the rail was saved from rupture, and the additional resistance to traction was prevented.

The hardest kind of chilled iron is the best material for brake blocks, for the purpose of wearing upon the flanges of the wheels. But it is not the best for stopping the car, for it does not "cling" to the wheel so well as softer iron does. Still, the brakes should have a sufficient degree of pressure applied to arrest the turning of the wheels.

In the construction of American cars, the best American white oak is used for the framework of the substructure, and the best white ash for that of the body. The life of a tramcar in America, properly maintained, is from 25 to 30 years. On the New York and Haarlem Tramway, cars placed there in 1857 are still running. Mr. Bancroft states that the wheels last for about 30,000 miles, and the axles for from 200,000 to 300,000 miles. On tramways of from 4 to 8 miles in length, with gradients varying up to 1 in 25, cars taking 80 passengers as a maximum load, are drawn usually by two horses; in very hot weather, a third horse is occasionally attached to assist the others on a steep incline.

The price of "top-seat" cars in America is about 11,000 dollars, or £229.

Mr. Martineau* gives the following table of the capacity and the weight of tramway cars and waggons :—

WEIGHT OF ENGLISH AND FOREIGN CARS, CONSTRUCTED BY THE STARBUCK CAR AND WAGGON COMPANY.

	Weight.		
	cwts.	qrs.	lbs.
CARS :—			
London, car to seat 22 in and 22 out	49	3	0
Hoylake ,, 22 ,, 24 ,,	46	3	7
Birkenhead ,, 22 ,, 24 ,,	47	1	14
Oporto ,, 20 ,, 20 ,,	40	2	0
Middlesbro' ,, 16 ,, 16 ,,	34	0	0
Naples, open car, with 5 transverse seats, to seat 20	21	1	20
Naples, car to seat 12 inside only (with partition)	26	3	14
,, ,, 16 ,,	34	0	0
Brussels ,, 16 ,,	34	0	0
Middlesbro' ,, 14 ,,	24	1	0
Sheffield ,, 16 ,,	29	0	0
Leeds ,, 18 ,,	31	0	0
TRAMWAY GOODS WAGGONS :—			
Pernambuco waggon	29	2	11
Oporto open goods	27	1	0
,, covered goods	32	1	0

Note.—The weights above given include wheels and axles.

---

* *Proceedings of the Institution of Civil Engineers*, vol l., page 42.

From this statement, it appears that the weight varies from 2½ tons for a full-sized car carrying forty-six passengers, to 24 cwt. for a light one-horse car carrying fourteen inside. Some heavier cars, not mentioned in the table, have been made for Russia, weighing 3 tons. They were made with wrought-iron underframing, iron panels, and elliptic springs. The bearing-springs of tramcars are most commonly made, wholly or partly, of india-rubber; but it had been found that they would not bear the extreme and lasting cold of a Russian winter, for which steel springs are indispensable. Steel springs, in connection with screw-brakes, which are preferred by Russian engineers, make the Russian car, of course, a heavier vehicle than English cars.

Light one-horse cars are used in England—principally at Sheffield, Leeds, and Leicester. They are also much used on the Continent—in Naples, Oporto, Antwerp, and Brussels—and it appears that they are extending in use, and are replacing the two-horse car with roof-seats, or an "imperial," as the upper stage is designated. As Mr. Martineau justly observes, there can be no doubt that the heavy weight of roof-seats, with a number of people on them, strains the framework of a car, in starting and stopping, and that, therefore, cars made without such seats last the longest. It has been said that the essence of a tramway is to keep up a continuous flow of traffic, so that, if possible, a car should always be in sight; and the principle of continuity of service may often be more economically maintained by means of one-horse cars than by heavier cars with two horses.

Taking wide averages, it may be stated that the number of passengers carried per mile run by cars is seven. The signification of this statistical item is, that seven passengers are taken up and set down per mile run by each car. Supposing that a car, going 70 miles in a day, makes four stoppages per mile-run, for passengers and interruptions, it would be stopped and started nearly three hundred times a day. When it is reflected that a 2½-ton car fully loaded with passengers, becomes a moving mass equal to 6 tons in weight—or, half loaded, upwards of 4 tons—it is clear that the duty of arresting such a heavy mass, with the resumption of motion, entails a vastly greater internal stress, comparatively, than is borne by ordinary 30-cwt. omnibuses, or even by railway carriages. Railway carriages, themselves strongly framed though they be, shake loose in the framework. The elastic oscillation of the body framing of these may be observed at the doorways, in many instances, when a train is started, if the valve-gearing of the locomotive be not equally adjusted so as to generate an even pull on the train.

But there is the patent objection to the smaller cars, that what is fictitiously called the "dead weight" of the smaller car constitutes a larger proportion of the gross weight with passengers, than that of the larger car. It was seen, for example, that the 2½-ton car can carry 3⅓ tons of passengers—"paying weight"—whereas the 24-cwt. car can take little over a ton of passengers. Otherwise—

The 2½-ton car weighs 1·08 cwt. per passenger
The 24-cwt. ,, 1·71 ,, ,,

showing that the lighter car has 57½ per cent. more weight of material per passenger than the heavier car. There is a certain degree of force in the argument thus deducible in favour of the heavier car. But it may mislead. Suppose, on the contrary, that the heavier car conveyed on an average only as many passengers as the lighter car with its load, it might with an equal degree of plausibility be made to appear that the lighter car would be much the more economical, since there would be a gross weight of 4⅓ tons against only 3¼ tons for the lighter car. And, again, the lighter car employs only one horse, whilst the heavier employs two.

CHAPTER II.

INSIDE-AND-OUTSIDE PASSENGER TRAMCAR, CONSTRUCTED BY THE METROPOLITAN RAILWAY CARRIAGE AND WAGGON COMPANY.

THIS car—shown in Plate I. (Figs. 230 to 235)—was constructed for the North Dublin Street Tramways. It is suited to the railway and tramway gauge of Ireland—5 feet 3 inches. It seats 20 passengers inside, and 22 outside: total, 42 passengers. The weight of the car is about 2½ tons, equivalent to 1·19 cwt. per passenger. The weight of 42 passengers is 3 tons; and the gross weight, fully loaded, is 5½ tons.

The body of the car is 15 feet 3 inches long, and 6 feet 8 inches wide, outside measurement. It is about 10 feet 1 inch high to the roof seats, and the total height over all amounts to 11 feet 3 inches. The total length is 21 feet 3 inches, in which a length of 3 feet is allowed at each end for the platform. The length of the body, inside, is 14 feet 7½ inches, which, for 10 seats on each side, provides an allowance of 17½ inches per passenger. On the roof, the allowance per passenger for 22, or 11 on each side, amounts to about 16½ inches. The axles are placed at centres 6 feet apart.

The roof-seats are approached by a spiral staircase at each end. The inside seats are stuffed with the best curled horsehair, and covered with Utrecht velvet. The body is closed by a sliding door at each end. All the side windows, except two on each side, are fixed; these two slide downwards, and they are fitted in the slides with steadying springs. Sliding curtains are mounted on iron rods. Ventilation is provided by means of small hinged

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windows under the outside seats. Two lamps are fixed within the car.

The whole of the framing is of well-seasoned oak or ash, and the panels are of mahogany, ⅜ inch thick. The doors are of ash. The roof is covered on the outside with canvas, rendered thoroughly watertight with paint. The canvas is protected by boards or slats, forming footpaths for outside passengers.

The underframe consists of two side-soles, 3½ by 3 inches, two end-soles, 4½ inches wide and 3 inches deep, rebated for the floor-boards, and four cross-bats, 3½ inches wide, and 2 inches deep. The flooring-boards are 1 inch thick, let flush into the side-soles and end-soles. The corner-pillars are 3¾ inches by 4½ inches, rounded at the outer angles. There are seven intermediate pillars at each side, between which the side-windows are framed. The upper side-rails are 2½ inches square. The end-rails are 1½ inch thick, shaped to the form of the roof; and there are 16 intermediate roof-sticks, 1¾ inches square, placed at distances of 11 inches apart between centres. The roof-boards are ½ inch thick, and the flooring-boards on the roof are ⅝ inch thick. Each platform is carried by three cantilevers, 2¾ inches thick, and 5¾ inches deep at the middle, bolted to the underframe of the car.

The wheels and the axles, Figs. 236, 237, 238, are of cast steel. The wheels are 30 inches in diameter, and are each formed with six spokes; one of them is keyed fast on the axle, and the other is loose and revolves independently; it is formed with a nave 8 inches in length, hollow in the middle, making a receptacle for oil. The rim is 2½ inches wide, and is formed with a flange projecting 11/16 inch from the tread of the wheel, according to the section, Fig. 238. The axle is 2½ inches in diameter between the wheels, and 2⅝ inches in the naves of the wheels. The journals are 1⅞ inches in diameter, and 4¾ inches long. They are formed with flat ends, without collars, and they take their bearings endwise against steel wearing-plates, inserted in the axle-boxes. The diameter of the tread is 2 feet 6 inches next the flange, and it is ⅜ inch less at the outer edge, making a slope of 3/16 inch, or 1 in

24, on the face of the tread. The rim is ⅞ inch thick at the outer edge. The two wheels are placed on the axle at a distance of 5 feet 1¼ inches between the backs of the tyres, which is 1¾ inches less than the gauge of the rails; so that, deducting the thickness of the two flanges, ½ inch remains for play. When the wheels, therefore, stand centrally on the rails, the flanges are just ¼ inch clear of the rail at each side. This is an important point. It is necessary that the flanges of the wheels should not touch or revolve against the inner ledges of the rails; in order that any binding of the way, and increased resistance, and probable alteration of

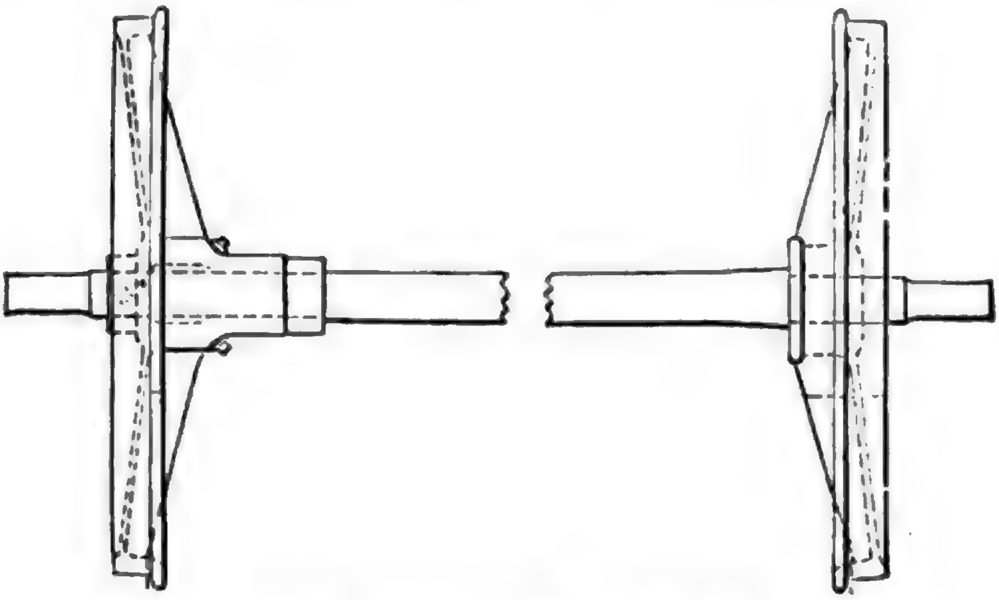

FIG. 236. Dublin Tramcar:—Wheels and axle. Scale 1/16.

gauge, or derailment, may be avoided. It is well, therefore, that the clearance between the flanges and the treads of the rails should be limited to what is just requisite for free circulation, and the whole remaining width of the groove given to the inside. There is another advantage in this disposition of the wheels, that detritus collected in the groove is the more easily pushed aside by the action of the flanges. The length of the axle between the centres of the journals is 6 feet 4 inches, being 13 inches larger than the width of gauge. The overhang of 6½ inches at each end —or 5 inches from the nave of the wheel—confers the advantage of some degree of elasticity of action, as between the rigid bearing of the wheel on the rail and the bearing of the axle-box.

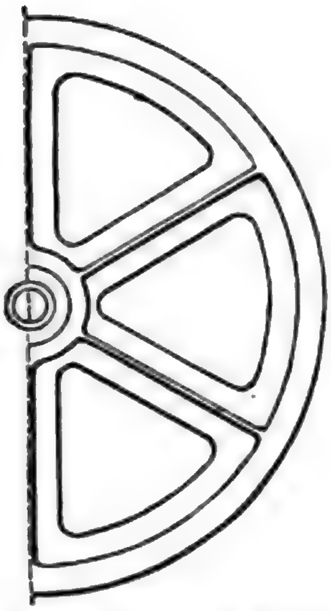

FIG. 237. Dublin Tramcar: — Side view of wheel. Scale $\frac{1}{16}$.

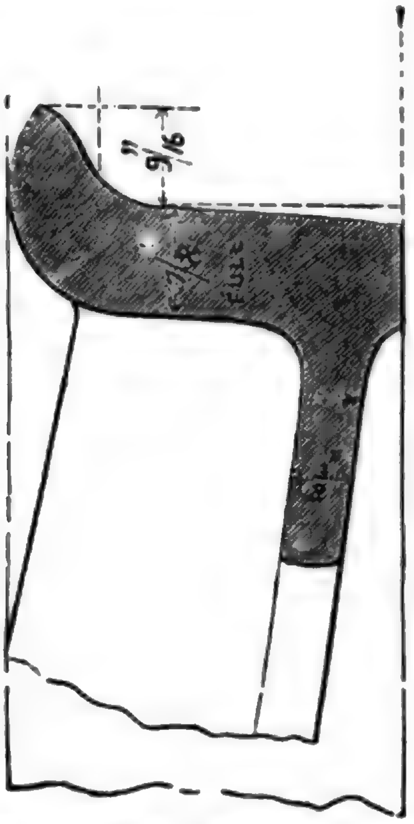

FIG. 238. Dublin Tramcar:—Section of rim of wheel. Scale $\frac{1}{2}$.

The axle-boxes, Fig. 239, are of American pattern; they are

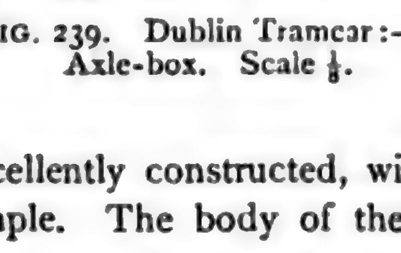

FIG. 239. Dublin Tramcar:—Axle-box. Scale $\frac{1}{8}$.

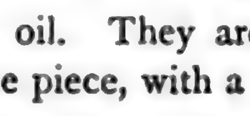

FIG. 240. Dublin Tramcar:—Section of brass bearing in axle-box. Scale $\frac{1}{4}$.

excellently constructed, with lubrication by oil. They are very simple. The body of the box is cast in one piece, with a receptacle in the lower part for cotton-waste, which is soaked with oil, and laps the journal below. The brass or gun-metal bearing, Fig. 240, is formed with a hollow in the upper side, as a receptacle for oil, which is introduced through a hole in the top of the box, and is admitted upon the journal through two oil holes in the brass. The brass bears upon the journal for all its length, but is restricted to a narrow width of contact, about $1\frac{3}{16}$ inches, upon the journal: being five-eighths of the diameter. The horizontal area of the bearing-surface on one journal is ($4\frac{3}{4} \times 1\frac{3}{16} =$) 5·64 square inches, upon which the maximum load is a fourth of, say, 5 tons, or 2,800 pounds—equivalent to 500 pounds on the square inch of bearing-surface. Again, for the horizontal area of the journal, which amounts to ($4\frac{1}{2} \times 1\frac{7}{8} =$) 8·41 square inches, the maximum load is equivalent to 333 pounds per square inch. These are great amounts of pressure concentrated on a square inch of surface. They may be contrasted with the corresponding distribution of pressure on the axle-journals of railway rolling stock:—

	Tramway car. lbs.	Railway stock. lbs.
Load per square inch of bearing surface .	500	300
Do. do. of horizontal area of journal . . .	333	224

It may here be noted that the gross weight of the Birmingham Central double bogie car—say 8 tons—is distributed at the rate of 360 pounds per square inch of horizontal area of journals.

The excess of pressure in tramway cars is warranted by the limited speed of tramway traffic, with the frequency of stoppages. But there is another feature in this axle-box, of great utility—the grit-shield, made of papier-maché, which embraces the axle, and is let into a groove formed in the back of the axle-box. The shield not only excludes dust and dirt from the axle-box, but it also aids in preventing waste of oil.

The brass is free to slide laterally under the upper part of the axle-box, and is slightly rounded at the surface of bearing on the box. The needful end-resistance is supplied by the steel bearing-plate, already noticed, let into and sustained in vertical grooves in the front part of the box, to oppose the end of the journal, and limit the lateral play of the axle in the axle-boxes to an allowance of ⅜ or ½ inch. The journal is also free to slide laterally, to a limited extent, under the brass. The effect of all this freedom of action is, that the liability to binding or heating in the axle-boxes is reduced to a minimum, whilst the traction of the car is facilitated.

A portion of the front of the axle-box is readily removable, so that every part of the axle-box may be opened to inspection, and the brass withdrawn, or the stuffing renewed. The axle-box, as a whole, may also be withdrawn from the axle.

The axle-guards are of cast iron, bolted to the side-soles. They are formed with broad bearing-surfaces, to support the axle-box for its whole length, from front to back, and with a recess at each side of the axle-box, in which the bearing-springs are lodged. The springs are of india-rubber, two to each axle-box, manufactured by the North British Rubber Company. They are barrel-shaped, and placed on end, each of them between two dished washers, upon the lateral extensions of a wrought-iron saddle, which bestrides the axle-box. The side-soles of the car take a bearing upon the upper ends of the springs.

The bearing-springs are formed of a special compound of india-rubber, stiffer than pure rubber, so as to dispense with the aid of steel as an auxiliary. There is no need for steel in combination with rubber anywhere, provided that a sufficient area of base is obtained for the rubber. There is a pair of india-rubber springs over each axle-box, which are about 7 inches high, when unloaded, and 4½ inches in diameter at the middle. They are reduced in height ⅜ inch by compression under the empty car, under a net weight of, say, 2 tons. Divided over eight springs, the compressing weight per spring is ¼ ton—whence it is deduced that the springs yield at the rate of (⅜ × 4 =) 1½ inches per ton on each spring, in the first stages of compression. Under the net load of 5 tons, the load per spring would be (5 ÷ 8 =) ⅝ ton, and the total deflection would be (1½ × ⅝ =) nearly 1 inch for each spring.

The brake, on the system known as Stephenson's, of New York, is worked at the platform at each end of the car. A block of cast iron is applied to each wheel. The blocks are hung as two pairs, each pair on a transverse swing-beam, applicable to one pair of wheels. The beams, when not under pressure, hang free of the wheels. The power is applied by hand by turning a vertical iron shaft or spindle, on which a chain is coiled. The chain is connected to one end of a long intermediate transverse lever, pivoted under the centre of the car, from which, by pulling-rods pinned to it near the centre, the swing-beams and brake-blocks are pulled into contact with the wheels. The actual pressure applied to the wheels in this manner may be calculated from the dimensions of the brake-gear. The handle, or crank, has a radius of 10 inches, whilst the chain is coiled on the shaft to a mean radius of about ⅞ inch. Next, the chain pulls the intermediate lever at a radius of 22½ inches, measured from the central pivot, and the pulling-rods are connected at a radius of 4½ inches. Applying these data, the pressure applied at the handle is multiplied or intensified 72 times when it is transmitted to and applied to the wheels: calculated thus, in terms of the ratios :—

Ratio of	Inches.		Inches.
Handle to chain	10	to	⅞
Long lever to short lever . . .	22½	to	4½
Final ratio	225	to	3·94
or, Leverage of the power . .	57	to	1

Suppose that a man can apply, on emergency, a pressure of 56 lbs. to a crank-handle. The statical equivalent of this pressure at the handle is (57 × 56 =) 3,192 lbs. at the tyres of the wheels, or 1·42 tons. This is the breaking force that may be applied to the wheels; and, supposing that the coefficient of frictional resistance between the brake-blocks and the wheels is the same as that between the rails and the wheels, it would appear that the wheels may not be skidded by the application of this brake, even when the car is empty, when the weight is

2½ tons. Of course, with its complement of weight, as passengers, adding a ton and a half, and making up 3 tons gross, it is still less practicable to skid the wheels, unless the coefficient of friction of the brake-blocks is considerably greater than that upon the rails. In practice, the wheels can be skidded by the brake.

Framework of such tender scantling as that of the tramway car, with a contracted wheel-base, great overhang, and seat-room for a heavy load of passengers, it is needful to stiffen by means of truss-rods. The underframe is strengthened by a trussing of iron bars applied under the seats, with tightening screws at the ends, under the side-soles; and by tie-bars and diagonal rods connecting the axle-guards and the side-soles. The roof, too, being of the form of an interrupted arch, to make a support for the roof-seats, requires to be trussed; and in order to stiffen the roof, a segmental truss-rod is applied at each side, suspended between the ends of the body, and clasped to the roof-ribs.

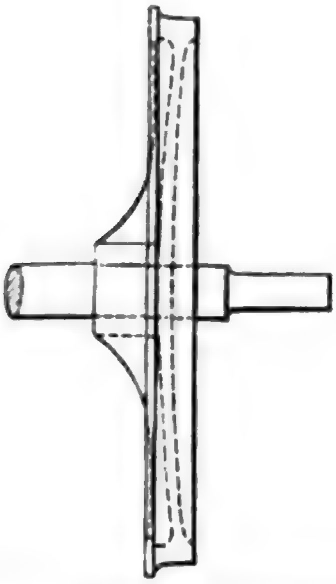
FIG. 241. Disc car-wheel and axle. Scale $\frac{1}{16}$.

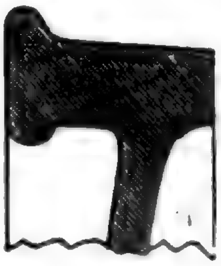
FIG. 242. Disc car-wheel. Section of tyre. Scale ¼.

The price of this car, to the Irish gauge, is £194, at the works; to the English gauge, the price of the car, of equal capacity, is £192 10s. The weight in each case is taken at 2½ tons.

The ordinary solid disc-wheels and axles employed by the Metropolitan Company for tramcars, are shown in Figs. 241, 242. The wheels are dished inwardly, with stiffening flanges on the back; they are 30 inches in diameter. The naves are 4 inches deep, and are simply driven tightly upon the axle, where they remain without the aid of keys. The disc is ⅞ inch thick at the nave, and is reduced to a thickness of ⅝ inch at the rim. The rim is 2¾ inches broad, comprising the thickness of the flange, ½ inch, and the width of the tread, 2¼ inches. The flange projects ½ inch from the tread; the axle is 3 inches in diameter between the wheels, 2⅞ inches in the naves; and the journals are 2 inches in diameter, by 5½ inches long.

CHAPTER III.

INSIDE PASSENGER TRAMCAR, CONSTRUCTED BY THE STARBUCK CAR AND WAGGON COMPANY.

THE passenger tramcar, to hold eighteen passengers inside, illustrated by Plate II. (Figs. 243 to 247), is an excellent example of its kind. The body is 14 feet long and 6 feet 7 inches wide, outside measure. The clear length inside is about 13 feet 3 inches, which, for nine persons on each side, contains an allowance of 17⅔ inches for each passenger. This allowance is liberal; in omnibuses, 16 inches only is allowed. The weight of the car is 31 cwt.; equivalent to 1·72 cwt. per passenger. The total length of the car, over the platforms, allowing 3 feet for each platform, is 20 feet; and the extreme height, above the rails, is 9 feet 3 inches. The gauge of the rails is 4 feet 8½ inches.

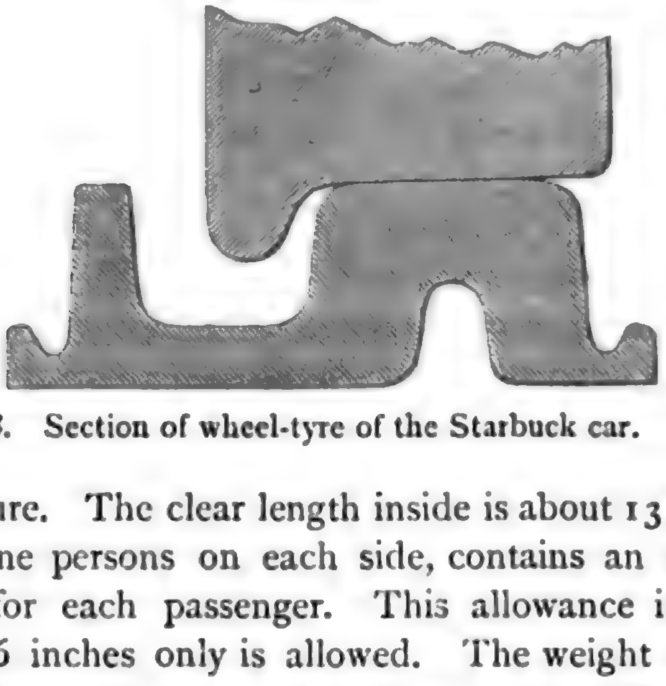

FIG. 248. Section of wheel-tyre of the Starbuck car. Scale ½.

The wheels are 2 feet 6 inches in diameter, of cast iron chilled at the tread and the flange, which are of the section shown in Fig. 248; the axles are 3 inches in diameter, and are of best scrap iron. They are placed at a distance of 5 feet 6 inches between centres. The bearing-springs are of india-rubber—two blocks to each axle-bearing. The brake is of the same design as that already described for the Dublin car; but the proportions are different, thus:—

Ratio of	Inches.		Inches.
Handle to chain	9	to	1
Long lever to short lever	24	to	3
Final ratio	216	to	3
or, Leverage of the power . .	72	to	1

For a pressure of 56 lbs. at the handle, the statical equivalent at the wheels is (72 × 56 =) 4,032 lbs., or nearly 2 tons—a considerably greater pressure, for a considerably lighter vehicle, than was found in the Dublin car. In short, the leverages are respectively as follows:—

Car.	Total weight half-loaded.	Leverage of brake.	Leverage per ton of weight.
Metropolitan . .	4½ tons	57 to 1	13·4 to 1
Starbuck . . .	3 ,,	72 to 1	24 to 1

Such variations of practice point to the greater strength and power of resistance to braking stress of the solid-roofed cars, relative to cars with interrupted roofs and top-loads.

at the tread and the flange, which are of the section shown Fig. 248; the axles are 3 inches in diameter, and are of iron. They are placed at a distance of 5 feet 6 inches between centres. The bearing-springs are of india-rubber—two blocks to each axle-bearing. The brake is of the same design as already described for the Dublin car; but the proportions different, thus:—

Ratio of	Inches.		Inches.
Handle to chain	9	to	1
Long lever to short lever	24	to	1
Final ratio	216	to	1
or, Leverage of the power	72	to	1

For a pressure of 56 lbs. at the handle, the vertical equivalent the wheels is (72 × 56 =) 4,032 lbs., or nearly 2 tons—a lerably greater pressure, for a considerably lighter vehicle, found in the Dublin car. In short, the leverages are ly as follows:—

Car.	Total weight half-loaded.		Leverage of brake.		Leverage per ton of weight.
Metropolitan	4⅓ tons	—	57 to 1	—	13·2 to 1
Starbuck	3 "	—	72 to 1	—	24 to 1

variations of practice point to the greater strength and power sistance to braking stress of the solid-roofed cars, relative with interrupted roofs and top-loads.

CHAPTER IV.

INSIDE-AND-OUTSIDE PASSENGER-CAR FOR STEAM TRACTION, CONSTRUCTED BY THE FALCON ENGINE AND CAR WORKS, LOUGHBOROUGH.

THIS car—shown in Plate III. (Figs. 249, 250), and further illustrated in Figs. 251 to 253—was constructed for the Birmingham Central Tramways, on a gauge of 3½ feet, to carry thirty passengers inside and thirty outside. It runs on eight 21-inch wheels, set in two swivelling bogies. The body is of the usual street car type, having a platform and staircase at each end, and an awning over the top seats. The dimensions are—

Length inside body, 20 feet ¼ inch, or 16 inches per passenger.
Length over platforms, 29 feet 1½ inches.
Width outside pillars, 5 feet 6½ inches.
Width over all, 5 feet 9 inches.
Height, 14 feet.
Distance apart of bogies, between centres, 19 feet 8½ inches.

The bottom frame is of oak, put together with white lead, and where necessary, with oak pins. Each side is trussed. The side and corner pillars are of ash. The waist panels are of Honduras mahogany, and the rocker panels of whitewood. The inner sides of the panels are covered with canvas glued on. The panels are pinned to every pillar, except the end pillars, to which they are screwed; they are glue-blocked to the battens.

The floor is of 1-inch red deal, tongued and grooved, nailed down to the bottom frame. Wearing grids are formed of longitudinal strips of white deal, nailed to the floor. The roof ribs are of American elm or English ash, bent to the curves and covered with pitchpine tongued and grooved. Canvas is put on with white lead, and painted outside with four coats of white lead paint. The doors have frames of cherry, panelled at the bottom with light wood and at the top with glass. They are hung on brackets and rollers at the top, and are fitted with friction-plates, handles, and catches.

The inside casings are framed together, and fitted with fancy wood patterns finished in their natural grain. A swing door with glass panel is fixed on the side where the car door slides in. The windows are of best polished plate-glass, and ¼-inch bare in thickness, fixed in grooved india-rubber. The blinds are of curtain form, of mohair mounted on polished brass rods. The seats and backs are of perforated veneer in one piece, suitably carved, finished in the natural grain, and French polished. The inside hand rails are of wrought-iron tube with screwed ends. They act as tension rods to keep the roof in proper form. A sufficient number of hand-straps are provided. There are two lamps, one at each end of the car. Their reflectors are fluted glass mirrors, showing a strong light to the car and a coloured signal light outside. Ventilators are fixed inside of the roof. Cords are provided to be connected with the gong on the engine.

The platforms are of 1-inch red deal, 4½ feet long. The frames and supports are of angle-iron, with oak bearers. The off-sides are railed in. The entrances are fitted with gates and locks. The flooring is either tongued and grooved or open-jointed. The steps are of hard wood, on wrought-iron brackets. The dash or fence is formed of wrought-iron rails supported by suitable standards, with a hand-rail at the top, and shut in outside. A light staircase is fixed to each platform to give access to the seats on the roof. The stair has sheet-iron stringers and risers and wood treads. The risers are flanged to receive the treads and secure the stringers.

The frames of the bonnets are of ash or American elm, bent to the curves, and covered with pine and canvas, as specified for the roof; fixed to the ends of the cars with wrought-iron brackets.

The top seats are of slat-and-space construction, with reversible

LATE III

backs. The slats are of pitch-pine or other suitable wood, varnished the natural colour. A light wooden roof covered with canvas is supported by iron standards. The upper part of each end is glazed and fitted with a deal door. Wearing slats of deal are fitted alongside the roof and across the bonnets. A light and strong hand-rail, 2¾ feet high, of wrought-iron tube with wrought-iron feet, all screwed together, is securely fixed round the top of the car and on the outer side of each staircase.

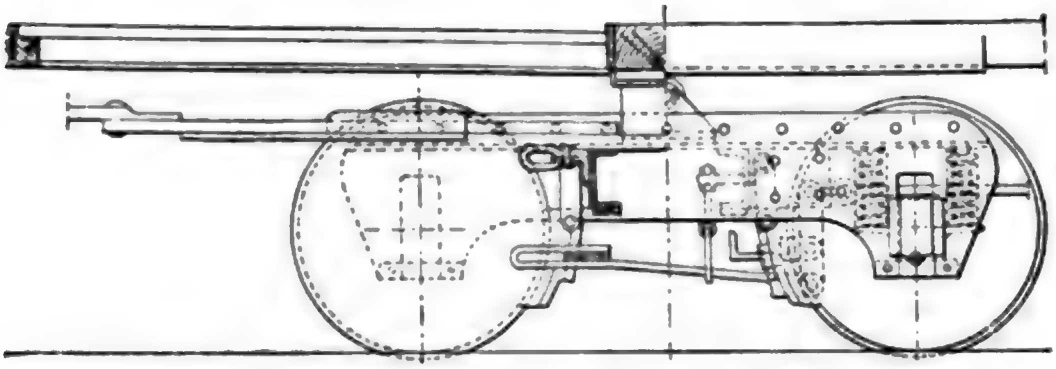

FIG. 251. Car for steam traction : bogie. Elevation.

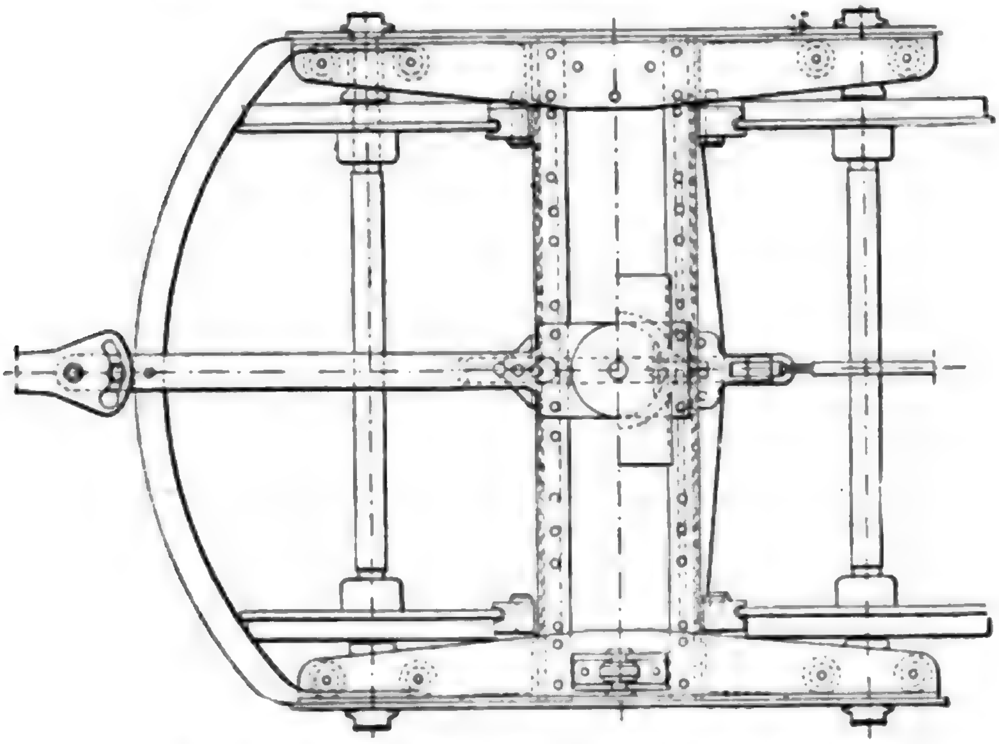

FIG. 252. Car for steam traction : bogie. Plan.

The bogies, Figs. 251 to 253, are of wrought-iron. The axles of each bogie are 3½ feet apart. The sides are cut out of ⅜-inch solid plates, forming guides for the axle-boxes. The centres are of cast iron, with convenient means for oiling. Friction rollers are fitted on each side to limit the tilting of the car. The wheels are of chilled cast iron, from America, 21 inches in diameter, bored to 2⅜ inches in diameter. The axles are of mild steel, turned, with 2¼-inch journals, having 5¾ inches length of bearing. The wheels are forced into their proper places on the axles by hydraulic pressure. The axle-boxes are formed with oil wells, and to exclude dust and dirt. The bearings are of gun-metal. There are double-spring check plates to limit end play. The lids are of wrought iron, fixed with a hook at the top and a bolt at the bottom. The springs are of coiled steel. The deflection of the springs, when fully loaded, amounts to ¾ inch.

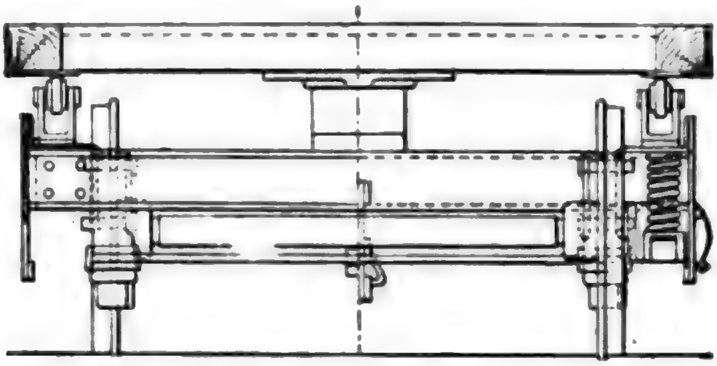

FIG. 253. Car for steam traction: bogie. End view.

A wrought-iron draw-bar is connected to each bogie as near as possible to its centre. Brake blocks of chilled cast iron, supplied one to each wheel; worked by means of a hand-wheel under the stair at each end of the car, and arranged to connect to the break-chain from the engine.

The iron work is of B B Staffordshire or other iron of equal quality. It is required to be of light but strong design and first-rate workmanship.

The outside of the car receives three coats of lead priming, eight coats of filling-up, stopped and rubbed down, painted, picked out, fine lined, and lettered according to colours, patterns, and wording, to be supplied by the purchaser. Finished with three coats of durable body varnish outside; and French polished inside, except the roof, which is varnished with finishing body varnish.

	Tons.	cwts.
Weight of car, unloaded	3	18
Do., fully loaded with 60 passengers, weighing 4 tons, at the rate of 15 passengers per ton .	7	18

The gross weight may be taken as 8 tons, or 2 tons per axle, or 1 ton per wheel. The total horizontal bearing area of the journals may be taken at 50 square inches, and the gross load at $\left(\frac{2240 \times 8}{50} =\right)$ 358·4, or, as a round number, 360 lbs. per square inch.

The weight of the car unloaded is 1·30 cwt. per passenger.

CHAPTER V.

RADIAL-AXLE PASSENGER TRAMCAR, BY MR. JAMES CLEMINSON.

Mr. Cleminson's system of three axles, forming a self-adjusting or "flexible" wheel-base, complies with the conditions of the problem of a free passage along curves in a satisfactory manner. The axles, with their axle-boxes, springs, and guards, are mounted in independent frames, one to each axle, separate from the main underframe of the carriage. The end frames are fitted with central pivots, on which they swivel freely, whilst the middle frame is so arranged that it can slide transversely. The three frames are connected together by articulated radiating gear, so that they act sympathetically, in such a manner that when the carriage or the car, leaving a straight portion of the way, passes on to a curve, the end axles are deflected horizontally, forming angles with the central axle, and taking up radial positions coincident with the radii of the curve. By means of such self-acting adjustment, the car rolls freely round the curve. When, conversely, the car passes from the curve to the straight line, the axles resume their parallelism, and the car rolls on naturally in a straight line. The automatic action arises from the translation of the middle axle and frame transversely, on a curve: the relative lateral movement of the middle frame is communicated to the near sides of the end frames, causing them to swivel on their pivots, and to turn the end axles into appropriate radial positions.

Mr. Cleminson's radial-axle tramcar, Fig. 254, has been at work on the Dublin and other tramways. The wheels are placed widely apart under the body of the car, and the pitching movement incidental to the working of tramcars constructed with the ordinary contracted wheel-base, is extinguished. This car seats 18 passengers inside, and 20 outside; total number, 38. The weight of the car is 45 cwt., equivalent to 1·18 cwt. per passenger.

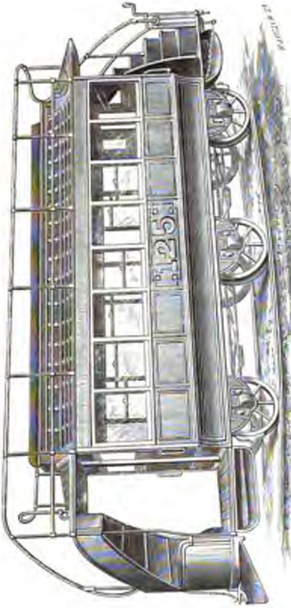

FIG. 254. Tramcar, fitted with Mr. Cleminson's system of radiating axles.

CHAPTER VI.

FRENCH TRAMCARS.

THE *winter car*, designed and constructed by M. Léon Francq, for the tramways from the Arc de Triomphe to the Porte Maillot, accommodates 14 passengers inside, and 7 standing on each platform; total number, 28. The weight of the car, empty, is 1·57 tons; with passengers, 3·36 tons.

	Feet.	Inches.
Total length, extreme	19	0
Length of the body	11	9½
Length of each platform	3	7¼
Length inside	11	5¼
Space per passenger, width	1	7½
Width, transversely, of seats	1	5
Height of seats	1	7¼
Width of passage way, between seats	2	9½
Width of body, outside	6	7
Width of doors	1	11½
Height of doors	5	11
Maximum height, inside	6	9½
Diameter of wheels (four)	2	4
Distance apart of axles, between centres	5	3

With dimensions so spacious, this car weighs only 1·12 cwt. per passenger, or about 4 per cent. more than the inside-and-outside car, described at page 360. The body is constructed as ordinary coach-work, with cross-bars of double T iron. The panels and the fences of the platforms are of sheet-iron, varnished. The springs were originally constructed on the Belleville system, consisting of dished steel plates, piled on a spindle; but they have been replaced by ordinary springs of india-rubber, barrel-shaped, like those already described, standing 8 inches high, and 4 inches in diameter at the middle. The brake is on Stephenson's system applied to all the wheels. The price of the car delivered was £180.

The resistance of the car to traction, on a level, varies from 13 lbs. to 22 lbs. per ton, according to the state of the way, at a speed of 7½ or 8 miles per hour.

The *summer car*, designed by M. Francq, has nearly the same leading dimensions as those of the winter car, and accommodates the same number of passengers inside and on the platforms. The sides and the ends of the body are open above the seats, but they are provided with curtains. The weight of the car, empty, is 1·37 tons, equivalent to 1 cwt. per passenger. The price of the car delivered was £160.

The Compagnie Générale des Omnibus use large omnibuses (see Plate IV., Figs. 255, 256), for inside and outside passengers, on the outer boulevards, on the line between the Etoile and La Villette. There are seats for 20 passengers inside, 22 outside, and standing room on the platform for 6 passengers; in all, 48. The body is 16 feet 5 inches long outside; the platform at the back projects 4 feet 10 inches beyond the body; the steps project 7 inches farther back; whilst the driver's seat in front projects 3 feet in advance. The total length of the vehicle is 24 feet 10 inches. The width of seat-space allowed in the interior is 19 inches per passenger; on the roof it is 17⅜ inches. The width of the body is 6 feet 7 inches outside. There is one staircase, at the end, leading to the roof, and the steps off the platform descend endwise. The body of the car is supported on transverse framing of wood, mounted on four wheels, 3 feet 3⅜ inches in diameter, at a distance apart of 7 feet 10½ inches. The wheels on one side of the car only are flanged, and are keyed on their axles; those on the other side are made with flat tyres, and are loose on their axles. The fore-wheels only are flanged; those on the other side are made with flat tyres. The fore-wheels run in a movable frame, to which traces for two horses are attached, and which turns on a perch-bolt, and admits of an easy passage on curves. The car rests on laminated springs, having a span of 39 inches. A brake, which can be turned by the driver, may be applied to the hind-wheels of the car. The cars run lightly, and the resistance to traction is much less than that of ordinary tramcars. The weight of the car empty is 2·95 tons, equivalent to 1·23 cwt. per passenger. The weight, when loaded, is from 6 to 6½ tons. The cost of the car, constructed at the works of the company, is £260.

The cars of the North Company are seated for inside passengers only: 16 inside, with standing room for 16 on the two platforms; in all, 32. The weight is 1⅜ tons empty, equivalent to 1 cwt. per passenger; the weight loaded is from 4½ to 4¾ tons.

The cars of the South Company are seated for 16 inside, 12 on the platforms, and 18 outside; in all, 46. The weight is 2·20 tons empty, equivalent to ·96 cwt. per passenger; loaded, the weight is from 5 to 5·20 tons.

Each car is worked with 8, 10, or 12 horses; each pair making a journey of 10 miles per day. The cars run from 53 to 56 miles per day.

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CHAPTER VII.

EADE'S REVERSIBLE CAR.

EADE's car, patented in 1877, was, in the same year, started on the Salford Tramways by the Manchester Carriage Company. The principal object in the design of this car has been to obviate the necessity for unfastening and carrying the draw-bar and pole from one end of the car to the other end, at the terminus;—a duty which is performed by a staff of men known as pole-shifters. The body of the car is swivelled centrally on the underframe, and can be turned round whilst the horses remain in harness, and the driver retains his seat. The body is secured in position by a simple locking apparatus. There is but one entrance to the car, at one end, and two staircases to the roof, one at each side of the entrance. The entrance is reached by three steps, one more step than there are in ordinary cars, as the body is more elevated than is usual. The windows are at a higher level than is usual, and they are considered to be safer. The driver occupies an elevated seat in front.

The body is seated for 16 inside passengers, and 18 outside passengers; in all, 34 passengers. The body is 12 feet long, and 6½ feet wide, outside measure. It is 11½ feet long inside, giving 17¼ inches per seat. The seat-room outside is 12 feet long, and, for 18 passengers, is equivalent to 16 inches per passenger. The total length from the front of the dash-board to the end of the staircase, is 17 feet 6 inches. There are four 30-inch wheels to the car, constructed with cast-iron nave, wood spokes and rim, and a flanged steel tyre. One wheel on each axle runs loose, and it is said that the traction is sensibly eased by the additional freedom of movement thus secured. The side-springs are ordinary laminated steel springs as used in omnibuses. A brake block is provided for each wheel, constructed of wood, secured by four 1-inch iron bolts, which take a bearing with the wood on the wheel. This construction of wood and iron, it is stated, bites more keenly than either wood or iron alone.

The weight of the car, empty, is 34 cwt., equivalent, for 34 passengers, to 1 cwt. per passenger. So low a ratio as this has not been attained in any other English car of the same capacity. The comparative lightness of the car is attained by employing framework of light scantling, wheels of wood, and smaller axles.

It is reported that there is, by the use of the reversible car, a saving of over 30 per cent. in horse-power; inasmuch as the car can be worked with a stud of 8 horses as efficiently as the ordinary car with 12 horses. Additional cars on the same design have been constructed for the service.

CHAPTER VIII.

BEARING SPRINGS.—WHEELS.—ROAD-AND-RAIL WAGONS.

BEARING SPRINGS.

THE calculations for the depression of side-springs, at page 365, are but roughly approximate, for the rate of compression or deflection of such springs diminishes as the load is increased. For instance, for the barrel-shaped india-rubber springs manufactured by George Spencer & Co., for tramway cars—7 inches high, $4\frac{3}{8}$ inches in diameter at the middle, and $2\frac{7}{8}$ inches in diameter at the ends—the deflections, or reductions of height, for given vertical loads are as follows:—

GEORGE SPENCER & CO.'S INDIA-RUBBER SPRINGS.

Load.	Total height.	Maximum diameter.	Deflection, or reduction of height.
Tons.	Inches.	Inches.	Inches.
0	7	$4\frac{3}{8}$	0
$\frac{1}{2}$	$5\frac{3}{16}$	$4\frac{3}{4}$	$1\frac{13}{16}$
1	$4\frac{1}{16}$	$5\frac{1}{4}$	$2\frac{15}{16}$
$1\frac{1}{2}$	$3\frac{3}{8}$	$5\frac{1}{2}$	$3\frac{5}{8}$
2	$3\frac{1}{4}$	—	$3\frac{3}{4}$

For a similar spring, of the same manufacture, 7 inches high, $5\frac{7}{16}$ inches in diameter at the middle, and $3\frac{7}{8}$ inches in diameter at the ends, the deflections were as follows:—

Load.	Total height.	Maximum diameter.	Deflection, or reduction of height.
Tons.	Inches.	Inches.	Inches.
0	7	5 7/16	0
½	5½	5⅝	1½
1	4¾	—	2¼
1½	4 3/16	6⅜	2 13/16
2	3 13/16	6⅞	3 3/16

The deflections in the last columns increased less rapidly than the loads, insomuch that the rates of deflection per ton of load, under increasing loads, were as follows:—

Load.	Deflection per ton of load.	
	1st spring.	2nd spring.
Tons.	Inches.	Inches.
0	—	—
½	3⅝	3
1	2⅝	2¼
1½	2¼	1⅞
2	1⅞	1⅝

Under a load of 5¼ tons net, eight of these springs would have each to support ⅔ ton, corresponding to an elasticity measured by about 3⅜ inches per ton for the first spring, and about 2¾ inches per ton for the second spring. These deflections are much greater than those of the North British Rubber Company, page 365.

It appears from the results of the deflections of Mr. Spencer's springs that the elasticity under a load of 2 tons is only about half of the elasticity under a load not exceeding half a ton. Also that the deflection is inversely as the cube-root of the quantity of material in the springs. For, the diameters of the springs are respectively 4⅜ inches and 5 7/16 inches, of which the squares are as 2 to 3, and are as the quantities of matter in the springs. Now, the deflections under 2 tons of load, are 1⅞ inches and 1⅝ inches;

and $\frac{14}{8} : \frac{12}{8} :: \sqrt[3]{3} : \sqrt[3]{2} :: 1·44 : 1·26$, or as 15 to 13. That is to say, the cube-roots of 2 and 3 inversely are as $1\frac{1}{4}$ to $1\frac{3}{8}$.

Further, as the quantities of material in the springs—being of the same height—are as the squares of the diameters, the deflections are inversely as the cube-roots of the squares of the diameters, or as the $\frac{2}{3}$ power of the diameter.

The quality of the india-rubber spring, whereby the resistance to compression increases more rapidly than the load, is in ordinary conditions objectionable; for it momentarily intensifies the resisting stress opposed to oscillations of the car fore and aft. It contrasts in this respect disadvantageously with the ordinary laminated spring, of which the increase of deflection is uniform for equal additions of load. But, under the actual conditions of a tramcar, placed on axles which are near together, with considerable overhanging masses at each end, the increasing rigidity of the springs under increasing pressure has a powerful influence to check the fore-and-aft oscillation of the car, and to reduce the extent of the oscillation.

The "rubber-centre spiral springs," manufactured by Messrs. L. Sterne & Co., offer a compromise between the uniform increase and the accelerated increase of resistance to increase of load. A pair of their springs of the C pattern, suitable for tramway stock, is deflected 1·47 inches under a load of 1·785 tons, equivalent to ·86 inch per ton. The annexed table of deflections and loads, based on the results of experiments made by Mr. Kirkaldy, exemplify the compromise referred to, showing that the increase of rigidity is much less than that of springs made entirely of india-rubber. Each spring consists of a central core of india-rubber, 2 inches in diameter, within a helical steel spring, 3 inches in diameter outside, of $\frac{9}{16}$-inch round steel, made in $8\frac{1}{2}$ complete coils, to a length of 8 inches:—

Compression or deflection.	Load.	Total deflection per ton of load.
Inches.	Tons.	Inches.
·45	·446	1·00
·81	·892	·91
1·16	1·339	·87
1·47	1·785	·82
1·73	2·232	·77
1·89	2·678	·71
2·04	3·124	·65

It may be remarked that though the stiffness of the Sterne spring increases less rapidly than that of the Spencer spring, the Sterne spring is on the whole much stiffer than the Spencer spring.

The composite spring, Fig. 257, is a combination of a helical steel spring and two indiarubber cushions within the helix. The helix is made of $\frac{9}{16}$-inch round steel, 3 inches in diameter outside. The cushions are slightly apart until a given load is reached, when they come into action as auxiliary springs.

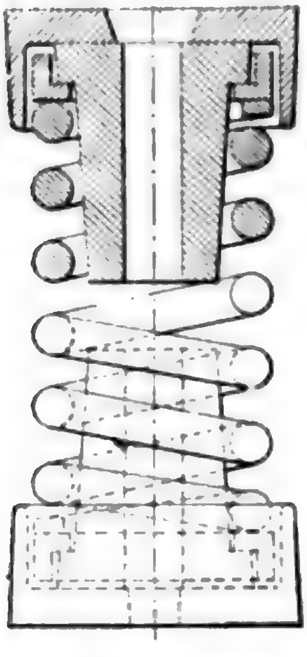
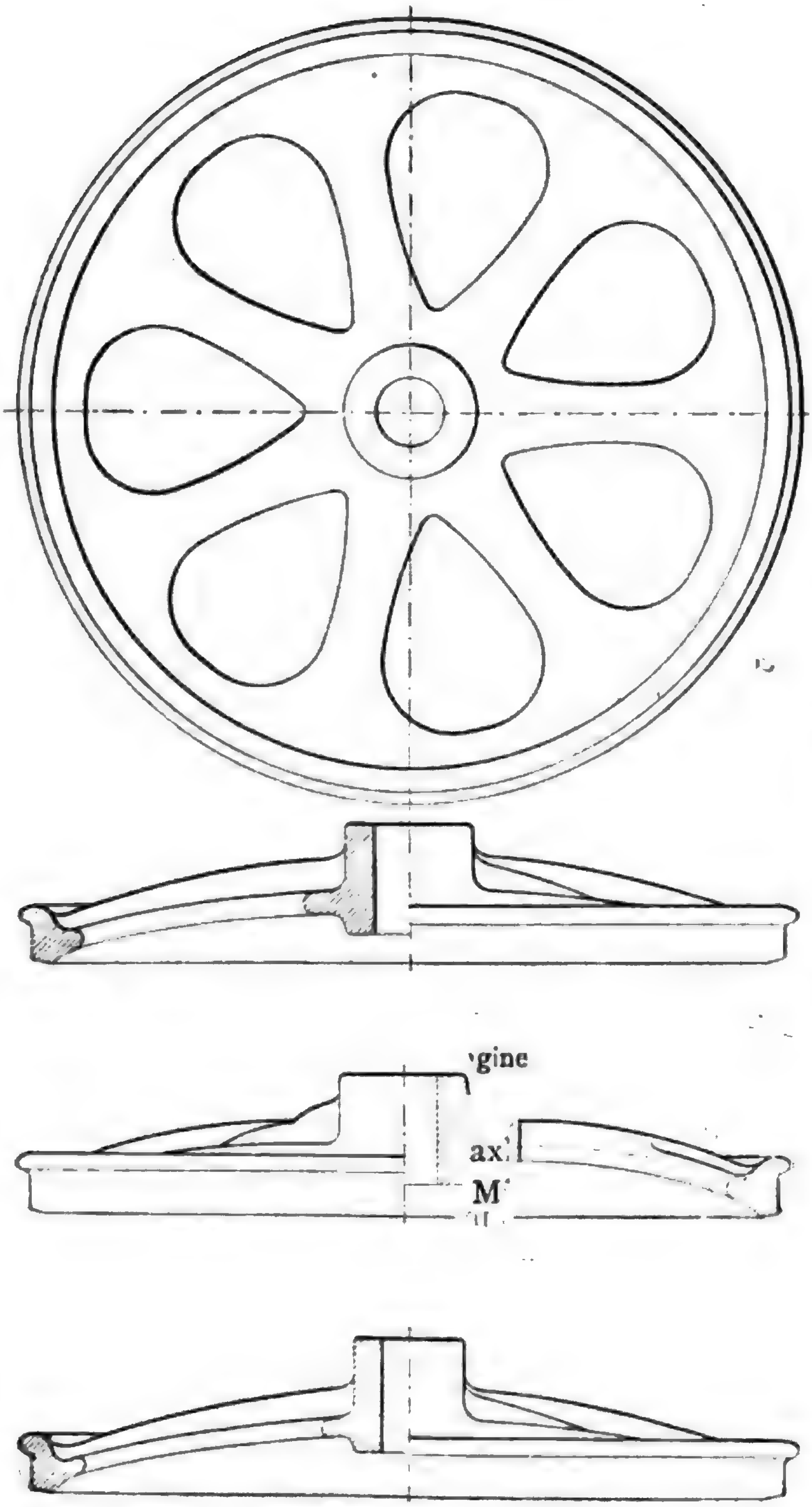


FIG. 257. Composite Spring with India-rubber Cushions.

Cast-iron wheels, chilled at the periphery, are extensively used for tramway cars. A quality of charcoal iron is secured which admits of crystallisation and chill going to a remarkable distance into the grain of the iron. In the earlier experience of tramways in London, car-wheels lasted fourteen months, performing, say, from 22,000 to 25,000 miles run. They weighed, when new, about 214 pounds, and they lost in weight from 14 to 16 pounds by wear—chiefly by the action of the brake. They failed by the breaking-off of the flanges.


No 2.
No. 3.
No. 2.
No. 1.

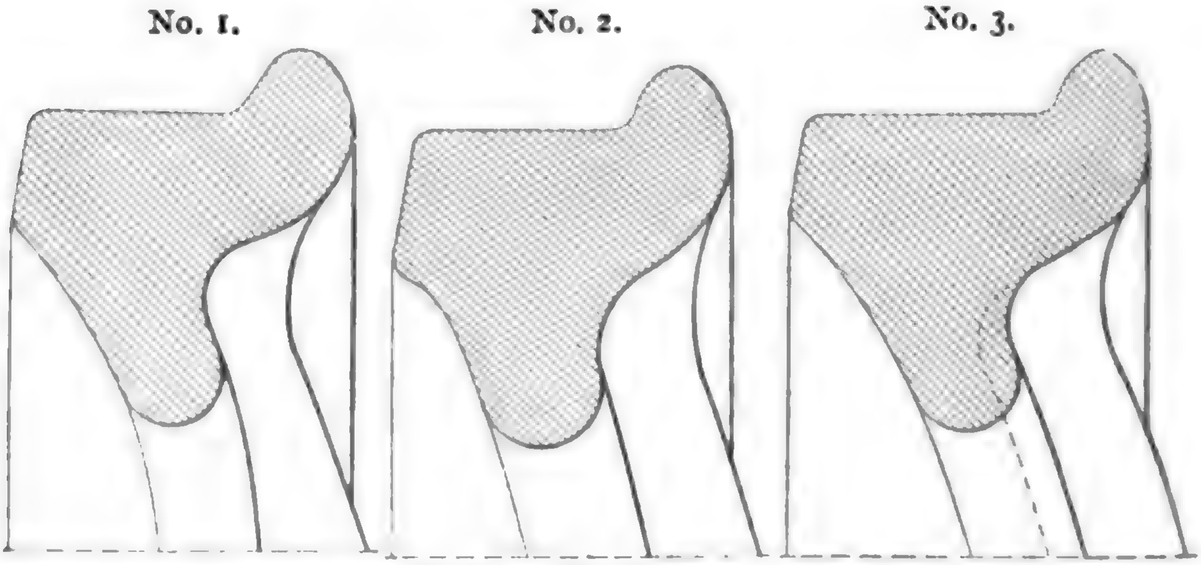
FIGS. 258 to 261. Miller & Co.'s Car Wheels.

CAR WHEELS.

The three varieties of wheels of chilled cast-iron—Figs. 258 to 261, and Figs. 262 to 264—manufactured by Messrs. Miller & Co., Edinburgh, are cylindrical at the tread, 30 inches in diameter, and have seven spokes.

No. 1, light, for one-horse cars: 2$\frac{3}{16}$ ins. wide at the periphery
„ 2, medium, for two-horse cars: 2$\frac{3}{16}$ „ „
„ 3, heavy, for two-horse cars: 2$\frac{5}{16}$ „ „

The flange stands $\frac{7}{16}$ inch high on the periphery, and is struck at the summit with a radius of $\frac{9}{32}$ inch. The nave is 2 inches in bore, 4½ inches deep, for No. 1; 2½ inches by 4½ inches for No. 2; the same for No. 3. The spokes form up the web of the wheel, which is $\frac{11}{16}$ inch, $\frac{13}{16}$ inch, and $\frac{15}{16}$ inch thick. They are 2¼ inches, 2¼ inches, and 2½ inches in minimum width, and are fortified by stiffening ribs on the back, one to each spoke.



FIGS. 262 to 264. Miller & Co.'s Car Wheels. Sections of rims.

The average depth of chill on the periphery of the wheels of Messrs. Miller & Co. is ¾-inch, which is sufficiently great to admit of a reduction in diameter by wear of from 1 inch to 1½ inches before the wheel is worn out: corresponding, it is stated, to a mileage-run of from 30,000 miles to 70,000 miles, dependent on the working conditions; as the state of the rails, gritty roads, level or hilly roads, with use of the breaks. A mileage-run of at least 50,000 miles is frequently attained by Miller & Co.'s wheels.

The height of the wheel-flange where narrow-grooved rails are employed is commonly ¾ inch. On some foreign tramways ⅝-inch flanges are used.

The steam tramway car and engine disc wheel, Figs. 265, 266, is a solid disc-plate wheel, usually 21 inches or 24 inches in diameter, with ¾-inch flange.

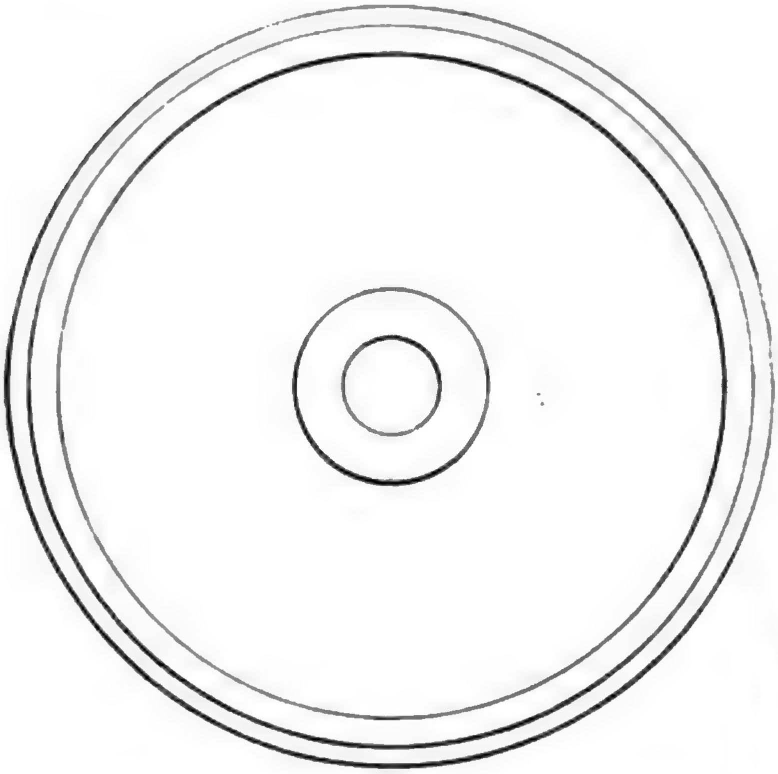


FIG. 265. Steam Tramway Car and Engine Disc Wheel.

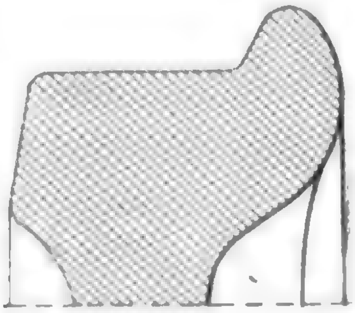
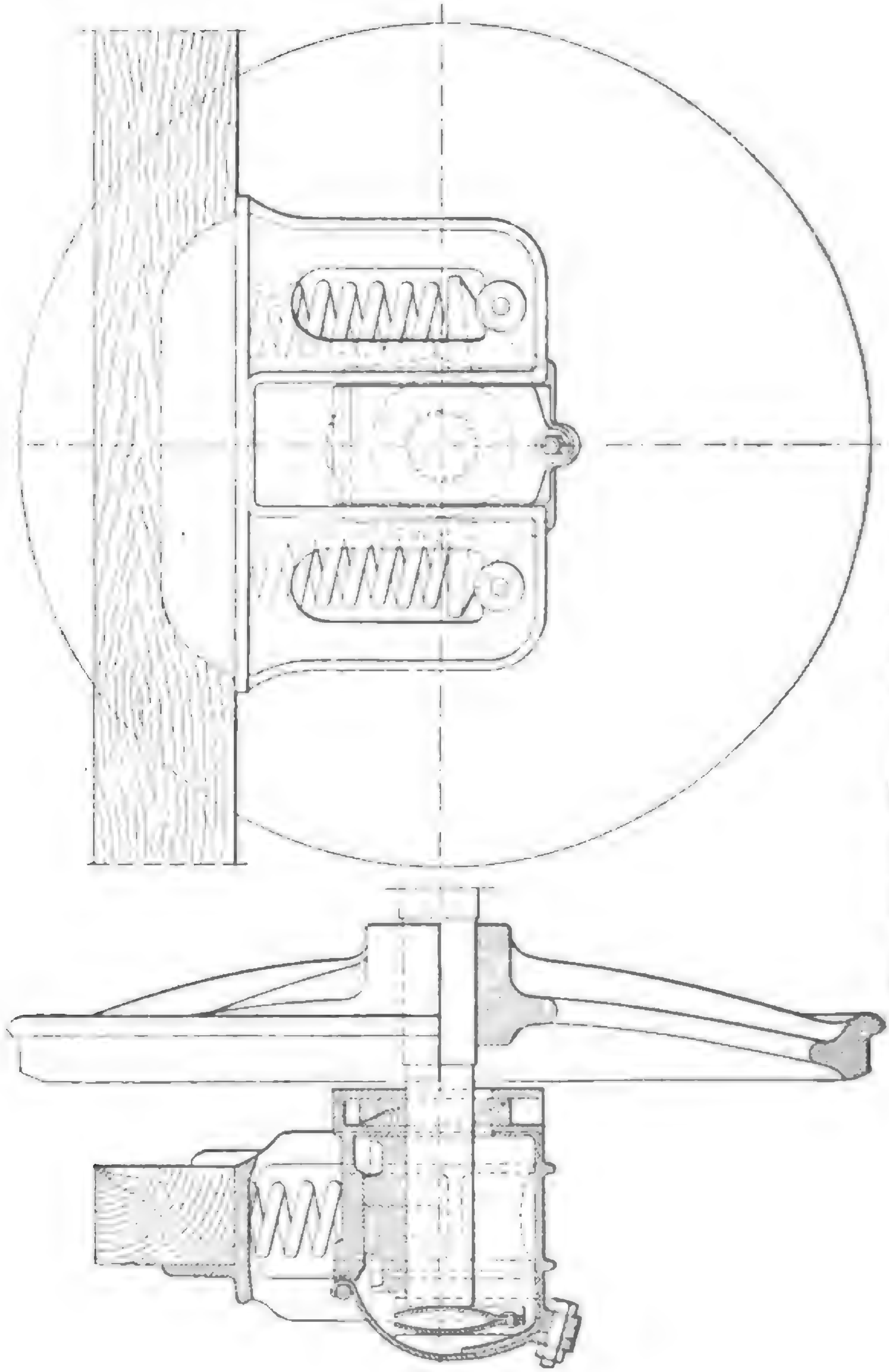


FIG. 266. Rim of Disc Wheel.

Combined views of the wheel, axle, axle-box, bearing springs, and guides, as constructed by Messrs. Miller & Co., are given in Figs. 267, 268. The class of axle-box has already been described in page 363. In the present instance the journal is 2¾ inches in diameter, with a bearing 5½ inches long, or twice the diameter. A pair of steel thrust-plates, having a limited horizontal elastic action, is inserted in the axle-box, between the end of the axle and the front of the axle-box. The vertical bearing stress is taken up by a pair of helical springs of 9/16-inch round steel, 2⅝ inches in



FIGS. 267, 268. Wheel, Axle, &c.: combined views.

diameter externally, and 7 inches high. An axle-box and guard, similar to those here shown in Figs. 267, 268, are shown in perspective in Figs. 269 and 270, of toughened iron. The axle is 2¼ in. in diameter in the wheels, and 2¾ in. in diameter between the backs.

The Handyside wheel, Fig. 271, which has been employed on railway rolling stock, is suitable for tramway stock. It is made in three parts—the tyre, the nave, or boss, and a pair of discs uniting the nave and the tyre. The tyre is of steel, or of chilled cast iron; the nave is of wrought iron, or of steel, with four radial arms. The discs are of cast steel, and are dished and

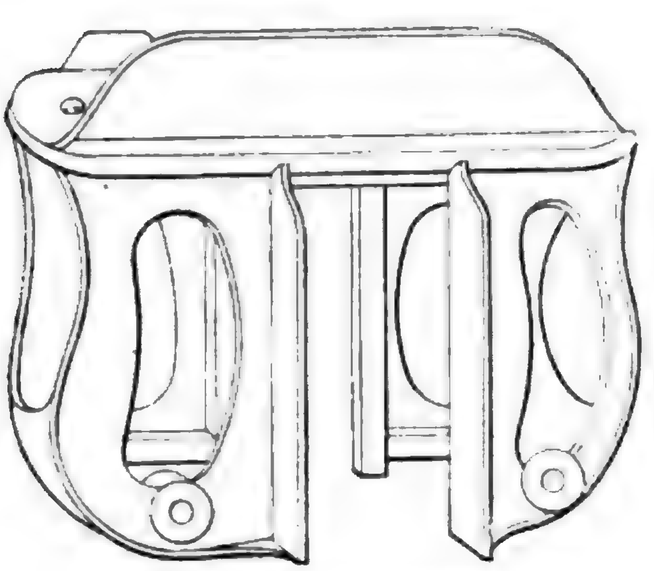


FIG. 269. Axle-guard.

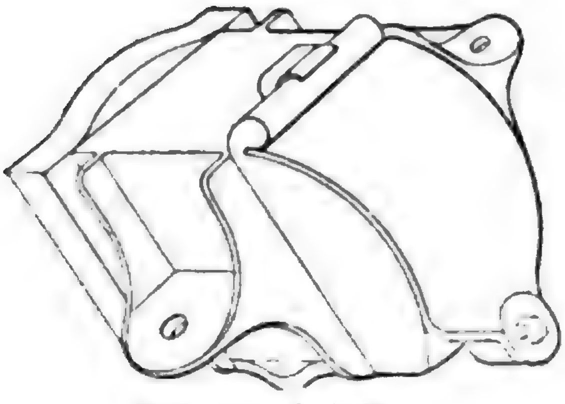


FIG. 270. Axle-box.

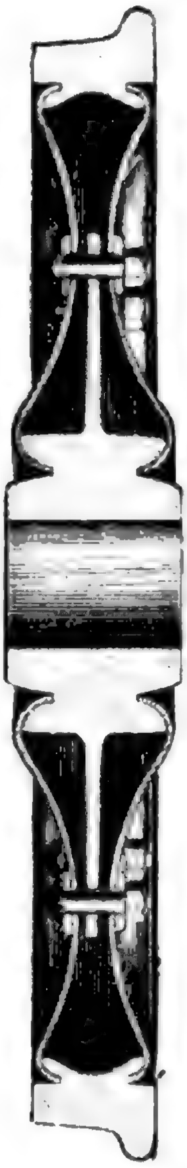


FIG. 271. The Handyside Car-wheel.

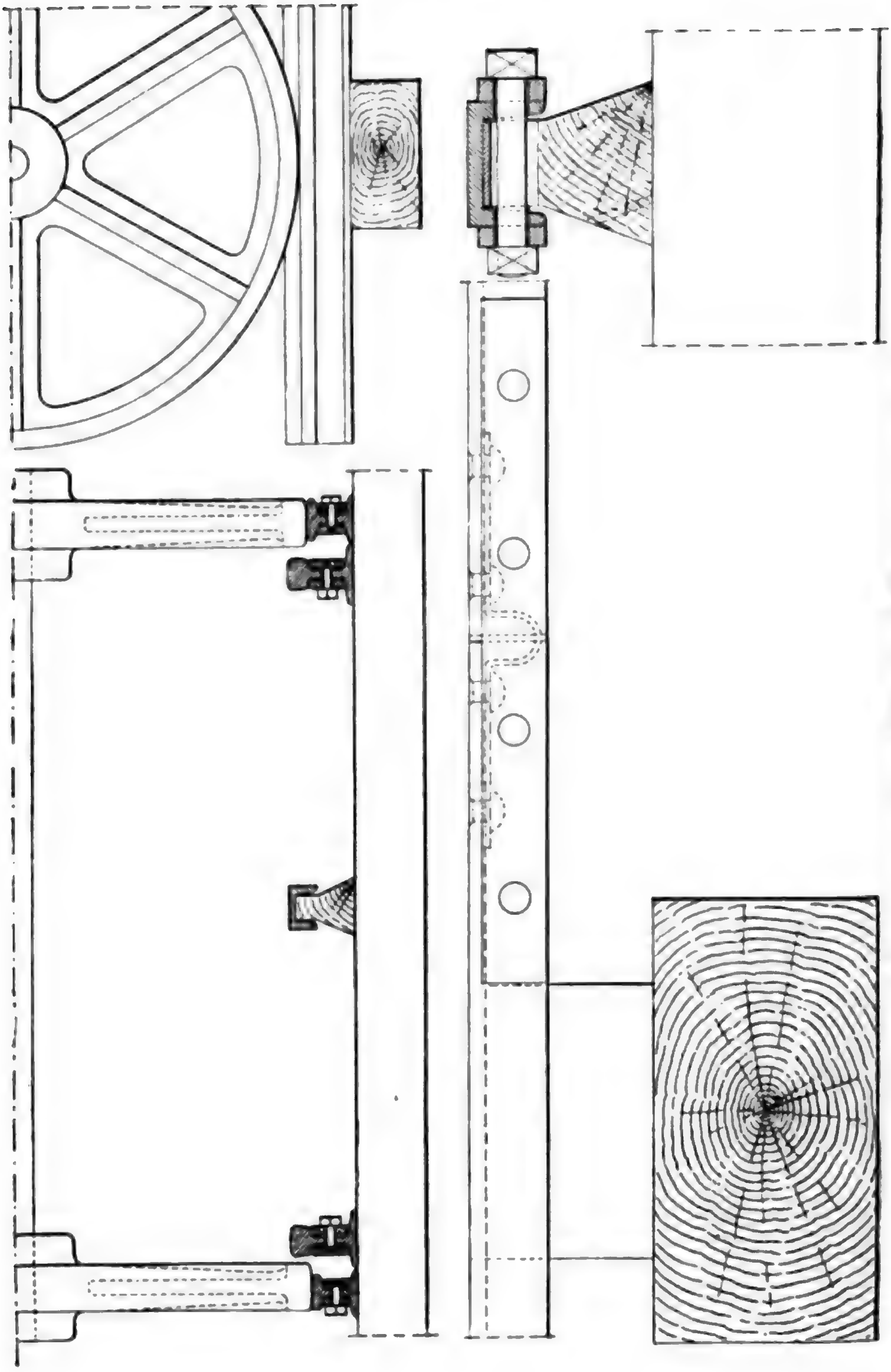


FIG. 272.—Bessbrook and Newry Tramway: Flangeless wheels and way.

turned inwards at the inner and outer circumferences. When put together, the edges of the discs embrace the tyre and the nave by corresponding flanges or lips, whilst at the middle, or half-radius of the discs, they close upon, but do not touch, the ends of the four arms. The discs are bolted together between two ring-washers at the bottom of the hollow, equally all round the nave; and as they do not touch each other, they are placed in a condition of elastic tension, at the same time that they firmly hold the tyre and the nave in position. The wheel has been well tested on the Caledonian Railway.

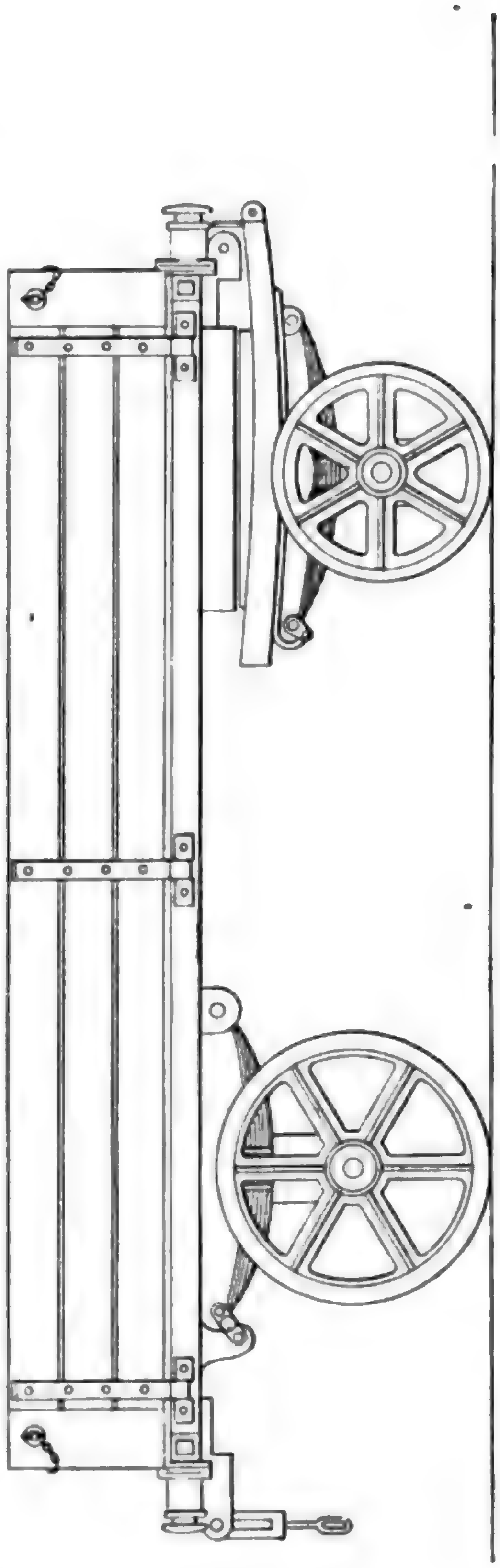


FIG. 273.—Bessbrook and Newry Tramway: Flangeless wheels and way.

ROAD-AND-RAIL WAGONS WITH FLANGELESS WHEELS.

Wagons used on the line can be adapted for use on the ordinary public road, so obviating transhipment, loading goods at the wharves, drawing them to the line by horses, and delivering them at any part of the mill premises. This system was originally suggested, in 1880, by Mr. Alfred Holt, and was worked out by Mr. Henry

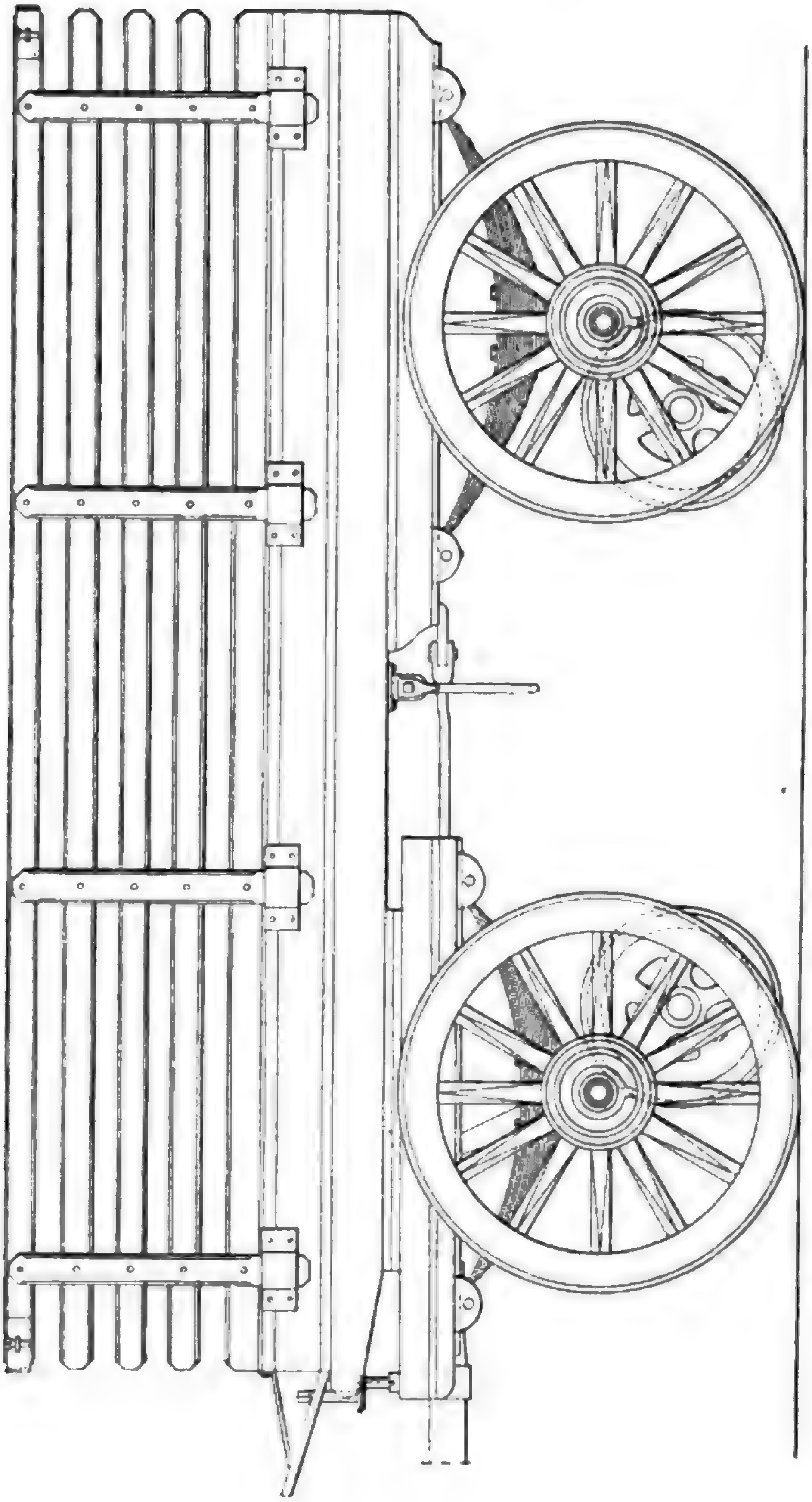


FIG. 274. Road-and-Rail Wheel Tramway Wagons in Staffordshire : Side elevation.

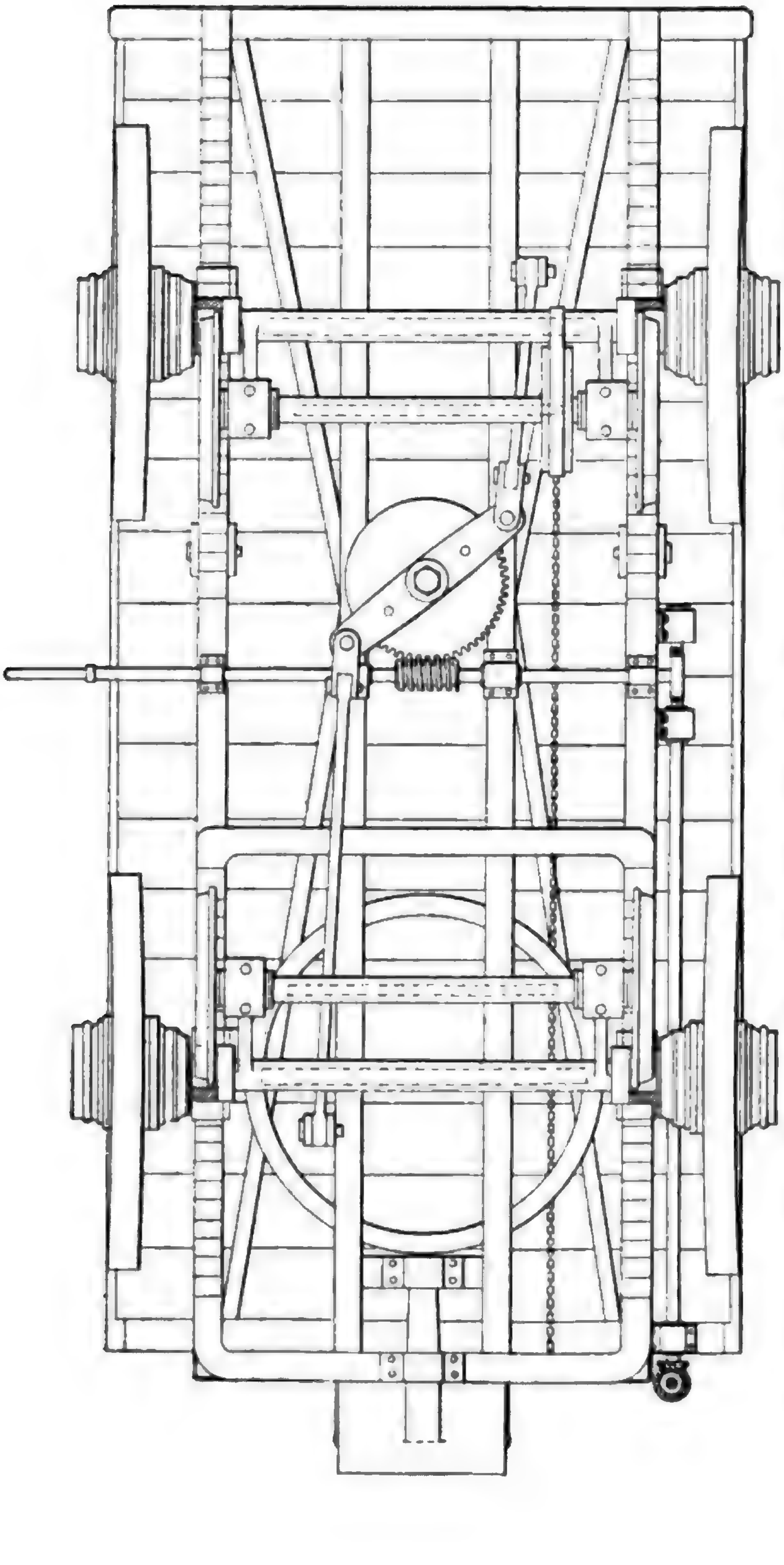


FIG. 275. Flangeless Road-and-Rail Wheel Tramway Wagons: Plan of under frame and changing gear.

Barcroft for the Bessbrook and Newry Tramway. The wheels of the wagons, Figs. 272 and 273, are without flanges, with tyres 2¾ inches wide, for running on common roads. The tram rails are of steel, 41¼ lbs. per yard, and outside these second rails, 23¾ lbs. per yard, are laid at a level ⅞ inch below that of the way, on which the plain wheels run, the ordinary rails forming the inside guard. The wheels are loose on the axles, and these work loose on journals. The wagon is supported on a fore carriage with a central coupling, which engages in a jaw in the fore carriage, to guide it when not pinned. Shafts are attached to the fore carriage when the wagon is to be used on ordinary roads. The wagon

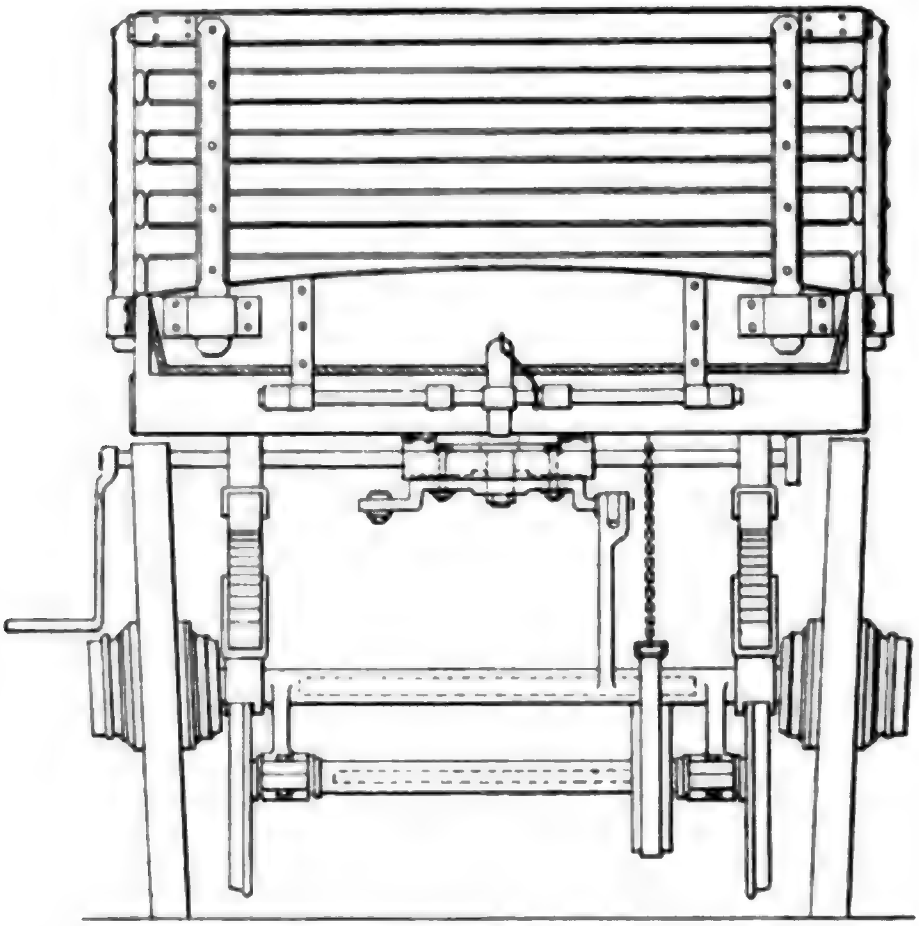


FIG. 276. Road-and-Rail Wheel Tramway Wagons: End elevation.

weighs, without the shafts, 23¼ cwt., and is constructed to carry 2 tons.

Flangeless wheels have been employed in another way, Figs. 274 to 276, on some of the road tramways in Staffordshire, on Mr. Dickinson's system, in which both road-wheels and rail-wheels are employed. When the road-wheels are lifted, the rail-wheels are lowered on to the rails; and conversely, when the rail-wheels are lifted, the road-wheels are lowered on to the road.

CHAPTER IX.

RESISTANCE TO TRACTION ON TRAMWAYS.

THE first and leading datum which rules the employment of mechanical power, is the resistance to traction on the tramway. On a railway, the resistance, under the most favourable conditions, may be as low as 6 lbs. per ton.[*] But, so low a resistance as 6 lbs. per ton is not to be hoped for on tramways, which, besides the difficulty of the groove in the rail, are exposed to the incidents of mud, stone, and dirt, and are made with many and quick curves. On a straight line of grooved rails, in fair order, the frictional resistance of a tramcar was found by Mr. Henry P. Holt to vary from a minimum of 15 lbs. per ton of the gross weight of the car, upwards, according to the weather and the state of the way, to more than 40 lbs. per ton :—indicative, certainly, of a bad order of conditions in this particular case.

His experiments were conducted on the Headingley line of tramway, at Leeds. It was laid, to a gauge of 4 feet 8½ inches, with a flat-grooved rail, on longitudinal and transverse sleepers, in concrete. A trial for the purpose of testing the resistance of a passenger-car, No. 21, by means of a dynamometer, was made on the 5th May, 1876. The barometer stood at 29·7 inches, and the thermometer at 53° Fahr. The day was dry, the way was in average condition, and the wind was north-west, slight. The direction of the way was for the most part due south, having two curves in it. The length of the line traversed was 1,645 yards, having a net rise of 115 feet, making an average ascending gradient of 1 in 43. The car was an ordinary four-wheel car, weighing 47½ cwts.; and it was loaded with 45 passengers. The wheels were 30 inches in diameter, 5½ feet apart between centres. The journals were 2½ inches in diameter. A section of the tyre of one of the car-wheels, and of the rail, as worn, is shown in Fig. 277. The load of passengers, allowing 14 to the ton, weighed 3·2 tons; making with the weight of the car, 2·37 tons, a gross load of 5·57 tons. The car was drawn by three horses over the greater part of the way; and, for a short distance, on an incline of 1 in 19, by four horses; at an average speed of 6 miles per hour. Two intermediate stoppages were made on the way. The average tractive force exerted over the whole length, deduced from Mr. Holt's continuous diagram of force, was 22·44 lbs. per ton of the gross load.

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[*] *Railway Machinery*, by D. K. Clark, 1855; page 297.

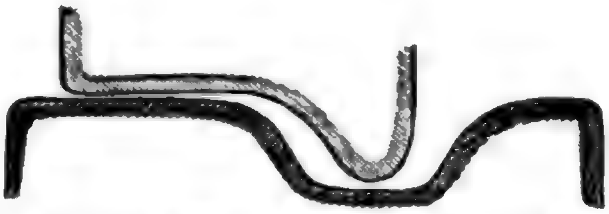

FIG. 277. Section of Tyre of Trial Car, and of Rail, Leeds.

Mr. Henry Hughes deduced from some experiments a tractive resistance of about 26 lbs. per ton; often much more, occasionally less. Such high resistances as these are readily explained, when it is considered that the flanges of the wheels frequently take a bearing on the floors of the grooves, or on the dirt embedded therein, at the same time that the wheels roll on the surface of the rail; for thus the wheel rolls on two different radii simultaneously, and grinding resistance is excited. Again, whilst the wheel at one end of an axle may be running on the proper bearing surface only, the wheel at the other end may be running on the flange, causing the car to swerve and grind laterally against the rails. Again, the rails may be out of gauge, or out of level, or weak and springy. Lastly, the grooves may be so clogged with detritus that all the wheels may be running on their flanges only; and, besides the illegitimate resistance due to traction on a mud surface, there is the extra resistance due to the wedging of the flanges in the dirt. Car-drivers know the value of a clear groove:—one may tell you that the car requires a horse more power to draw it over clogged rails; another will tell you that it is equivalent to some hundredweights more load, or a ton or two more, according to the clearness of his perceptions. The horse would be the best witness, if he could speak his mind, but, failing his verbal evidence, the dynamometer must be consulted.

It was directly proved by experiments made by M. Tresca, on the tractional resistance of a tramway car, that the groove in the rail was the direct cause of a large portion of the resistance to traction. The car, having four flanged wheels, with its load, was drawn over a portion of the Paris and Versailles Tramway, laid in macadam, when the tractional resistance amounted to 1-100th part of the gross weight, or 22·40 lbs. per ton. This quantity is precisely the same as that which Mr. Holt deduced from his trials. Subsequently, two of the flanged wheels, both on one side of the car, were removed and replaced by flat-tyred wheels, by M. Delonchant, the engineer of the tramway; and in July, 1860, M. Tresca repeated the experiment with the half-flanged car:—

	Tons.
Weight of 47 passengers, @ 143 lbs. . . .	3·00
Weight of wheels	0·41
Weight of the car	2·26
Gross weight	5·67

The length of line traversed was a third of a mile, on a level; and the tractive force, at a uniform speed of 7½ miles per hour, amounted to about 86 lbs., equivalent to 1-147th part of the gross weight, or to 15¼ lbs. per ton. Thus, the removal of two flanges was accompanied by a reduction of the tractive resistance by one-third. M. Delonchant, encouraged by the results of his experience, removed another flanged wheel, running the cars with only one flanged wheel, and three flat-tyred wheels. The result, according to M. Goschler, was that the resistance was reduced one half as compared with the original car with four flanged wheels. In this proportion, the tractional resistance must have been reduced to about 1-200th part of the gross weight, or to about 11 lbs. per ton.

The Vignoles rail, employed in the tramways of Moscow, incurs one-half less resistance to traction than the ordinary grooved rail, according to the report of the engineer, Colonel de Sytenko. The comparatively small tractional resistance of the Vignoles rail is clearly due to the absence of a narrow groove, but it has the objection of breaking the continuity of the pavement.

The resistance to traction at low speeds, increases, of course, with the speed, though slowly. On ordinary railways, under ordinary conditions of curvature and of maintenance, the resistance of engines and trains taken together, as deduced experimentally by the author, may be taken as follows:—*

12	lbs.	per ton,	at a speed of	1	mile per hour.
13	lbs.	,,	,,	10	,,
14	lbs.	,,	,,	15	,,
15½	lbs.	,,	,,	20	,,

Here it appears that the resistance increases only by 2½ lbs. per ton, when the speed is raised from 10 miles per hour to 20 miles per hour. It may be assumed that, on tramways, the speed will not exceed 15 miles, even when mechanical motive power is employed, and within such a limit the variations of tractive force with the speed are not worth serious consideration.

Considering that the experiment by M. Tresca, from which a resistance of 22·4 lbs. per ton was deduced, was made on a line of tramway laid in macadam, it may be inferred that the resistance on a straight line of tramway, made with grooved rails, well maintained in granite pavement, would not, under similar conditions, have exceeded 20 lbs. per ton.

Mr. Edward Woods, also, estimated the resistance of a tramcar on a level, and, it is presumed, a straight line, at 20 lbs. per ton.

In view of the foregoing observations, it may be concluded that, for purposes of estimation, the resistance of engines and cars on grooved-rail tramways, level, straight, and well maintained, is 20 lbs. per ton; and that on a line in average condition, with curves, it may occasionally amount to 40 lbs. per ton. An average of 30 lbs. per ton may be taken as a datum for the calculation of the ordinary tractive force to be provided for. These data coincide with the conclusions of Messrs. Merryweather & Sons from their experience with tramway locomotives and cars.

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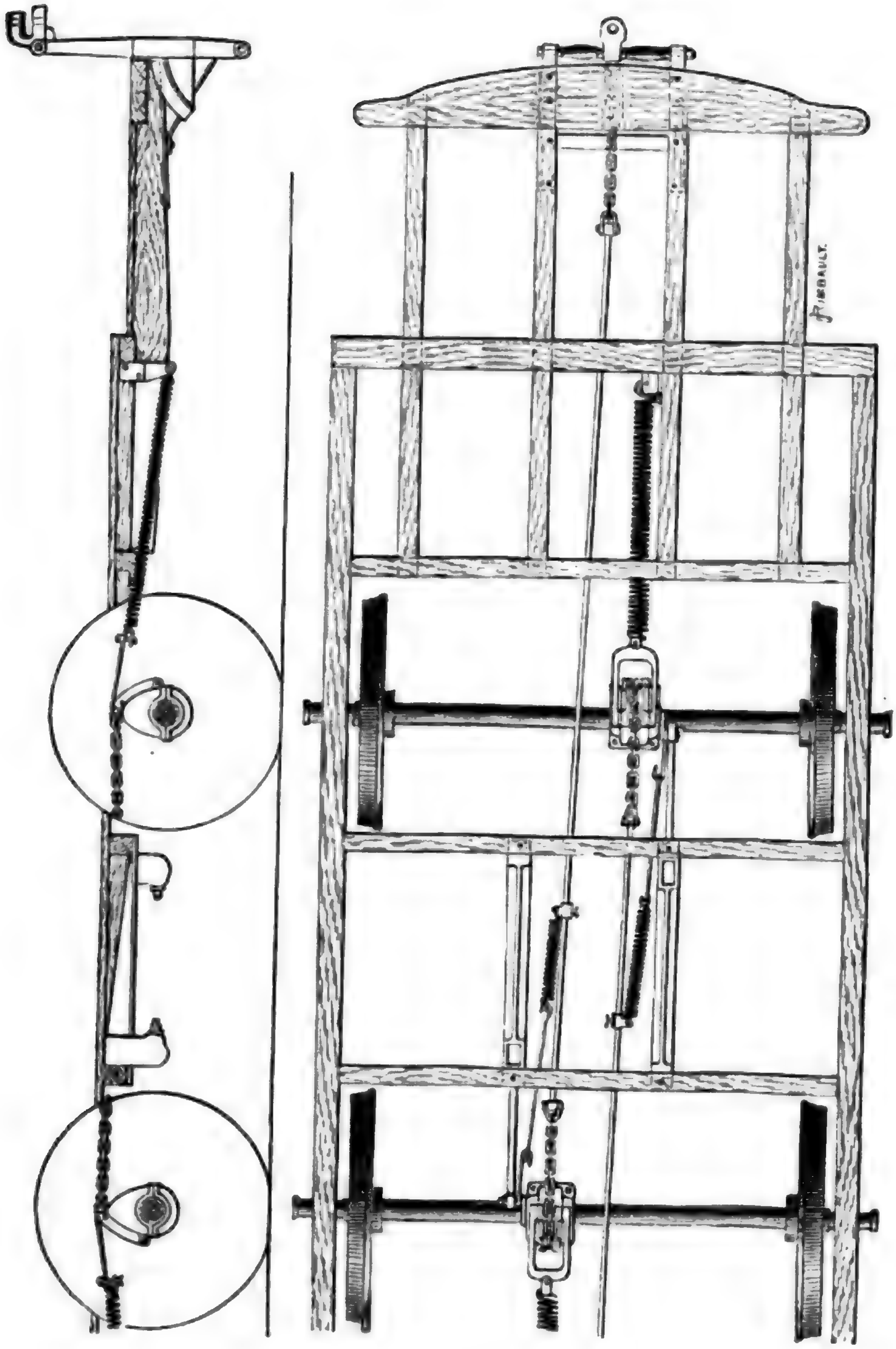
* *Railway Machinery*, 1855; page 310.

The force required to start a tram-car, to get up the speed, is necessarily greater than the force required to maintain the speed uniformly. It is a variable quantity, for it may be anything that horses may choose to exert, or that engine-drivers may apply. Mr. John Phillips found by experiment that in starting a car by two horses, an initial tractive force of from 500 lbs. to 600 lbs. was exerted on the car:—equivalent, for a gross weight of 5 tons, to from 100 lbs. to 120 lbs. per ton.

Mr. Holt found that the momentary initial force exerted by the horses in starting the load from a state of rest, was in three instances as follows:—in starting down an incline of 1 in 79, it was 450 lbs.; in starting up an incline of 1 in 62, it was 1,100 lbs.; and up an incline of 1 in 50, it was 975 lbs. Allowing for the force of gravity, the net initial efforts to start the car were 606 lbs., 900 lbs., 725 lbs. respectively; being at the rate of 110 lbs., 160 lbs., 131 lbs., respectively, per ton. These results accord with those which were found by Mr. John Phillips.

In order to obviate the straining, spavining, and weakness of back, to which horses are subject, caused by the effort of starting heavy cars, Mr. Henry P. Holt designed a tramcar starting gear, patented in May, 1879, illustrated by Figs. 278 and 279. A lever, to the upper end of which the horse is harnessed, is arranged vertically at each end of the car, pivoted at the lower end to a bracket fixed to the frame, and carrying a quadrant fixed to it about halfway up, corresponding to, and connected by a chain with, another quadrant formed as a cam, slung on the hind axle of the car (see Fig. 280). Enclosed within the quadrant, which is hollow, a ratchet-wheel is keyed fast on the axle, into which a pawl pivoted



FIGS. 278, 279. Tramcar Starting Gear, by H. P. Holt.

in the quadrant engages, when the pull of the horse is applied through the chain to the quadrant. The pull of the horse at starting is thus transmitted to the axle, and causes it to revolve. As the cam is upright at the instant of starting, it exercises a degree of leverage on the axle, by which the pull of the horse and the tractive force are multiplied. The pawl is released clear of the ratchet-wheel, after the car has been started, by means of a rod running through friction-discs contained in a fixed box. By these means, it is arranged that, at first starting, the horse travels at twice the forward speed of the car. The lever is controlled by springs, by which it is retained in a vertical position, or at right angles to the platform when there is no tractive pull. When the pull is applied to the lever, the springs through which the pull is communicated to the car, yield in proportion to the pull, and in so doing fall forward, and to a lower level, thereby augmenting the angle of the traces, and the downward stress on the horse, and so improving the foothold.

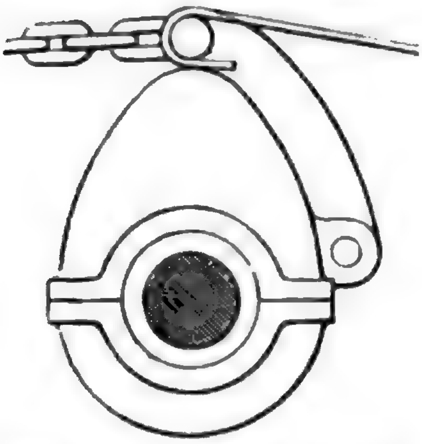


FIG. 280. Holt's Starting Gear—Cam Quadrant. Scale $\frac{1}{8}$.

For the ordinary momentary pull of 975 lbs., in starting on an incline of 1 in 50, a substituted steady pull—550 lbs.—is brought to bear by the instrumentality of the starting gear. Mr. Holt deduced as means of several experimental results, that the force exerted in starting a tramcar, weighing in all 5 tons, on a level, without starting gear, is 470 lbs., or 94 lbs. per ton; and with it, 213 lbs., or 43 lbs. per ton. Ascending an incline of 1 in 12, the forces are respectively 1,400 lbs. and 636 lbs.

The weight of two sets of starting gear for one car is 135 lbs.; the price is £18. Mr. Holt estimated that the working life of the tramway horse would be extended half a year by the employment of the starting gear. Thus the life which is usually 4½ years, would be extended to 5 years, equal to that of an omnibus horse.

Mr. E. Perrett experimented with a passenger-car, for 24 passengers, weighing 34 cwt., on four wheels $5\frac{1}{2}$ feet apart between centres, on the Nottingham tramways. The force, by dynamometer, required to start the car, and the force required to keep it moving, under different circumstances, were as follows :—

Grooves.	Line.	To start.	To keep moving.
		Per ton.	Per ton.
Clear . .	Straight and level	50 lbs.	25 lbs.
Very dirty .	Do. do.	66 ,,	50 ,,
Moderately dirty	Do. up gradient 1 in 130	106 ,,	66 ,,
Do. do.	Do. down do. do.	57 ,,	34 ,,
Do. do.	Curve, 45 feet radius up gradient 1 in 130	86 ,,	72 ,,
Do. do.	Down do. do.	62 ,,	50 ,,
Do. do.	Curve, 22 feet radius up gradient 1 in 130	132 ,,	94 ,,
Do. do.	Down do. do.	95 ,,	65 ,,

From this statement it appears that on a straight line the starting force varied from 50 lbs. to 80 lbs. per ton, according to the state of the rails—being less than those already mentioned. But it is probable that in this, as a private experiment, the starting was more gently effected than in the other instances. On the straight line, with clear grooves, the running resistance was 25 lbs. per ton; and this was doubled, or increased to 50 lbs. per ton, when the grooves were very dirty; or even when they were but moderately dirty, if the mean of the upward and downward pulls on the incline 1 in 130 be taken. Under the same condition, of moderately dirty grooves, the effect of a curve of 45 feet radius, averaged from the upward and downward pulls, was to raise the resistance from 50 lbs. per ton to 61 lbs. per ton; and that of a curve of 22 feet radius, raised it to 80 lbs. per ton. If 25 lbs. be deducted from each of the last three values, for the effect of dirt in the grooves, there remain 25 lbs., 36 lbs., and 55 lbs. per ton as the relative resistances with clear grooves, on a straight line, a curve of 45 feet radius, and a curve of 22 feet radius; showing that the resistance on a 22-feet curve is more than twice the resistance on a straight line. (For resistance of steam-car, see page 481.)

Mr. A. W. Wright[*] tested the tractional resistance of a car on the North Chicago City Railway—a tramway laid with step-rails, which are grooveless, like the Philadelphia rail (page 9). The car, with passengers, weighed 3 tons, and required an average force of 109½ lbs. to draw it at a speed of five miles per hour, including stoppages, or 36½ lbs. per ton, over old worn-out iron rails. On new steel rails, the traction force averaged 17 lbs. per ton. To start the car, a force of 148 lbs. per ton was exerted on the old rail, and 128 lbs. per ton on the new rail.

In view of the foregoing results, though based on scanty data, and the results of Mr. Holt's trials, with other data already given, the average resistance—30 lbs. per ton—already adopted for calculation, may be retained; although an occasional maximum of 60 lbs. per ton may be reached, and, on the contrary, a minimum of, say, 15 lbs. per ton, when the rails are wet and clean, straight and new.

The great degree of extra resistance due to the clogging of the grooves in the rails, compared with the resistance for clear grooves, has been referred to. These observations are corroborated by the experience of steam-power as well as of horse-power. Mr. J. Arthur Wright states that, on a dusty day, on the steam-lines of the Rouen Tramways, when, despite every effort to keep the rails clear, the grooves become filled with dust and dirt, the engines consume about 2¼ lbs. of coke per mile more than they do under more favourable circumstances—when the consumption averages about 12 lbs. per mile. The excess is nearly 20 per cent.

On this question of special tractional resistance, Mr. H. Conradi made some observations on the reduction of resistance due to the employment of his rail cleaner.[†] The gross resistance of each car at starting on muddy and dirty lines, straight and level, was from 80 lbs. to 90 lbs. After the starting the resistance settled down to from 60 lbs. to 70 lbs. On curves and passing places, of from 25 feet to 30 feet radius, the resistance was from 75 lbs. to 85 lbs. On very steep gradients and curves of this radius the resistance varied from 90 lbs. to 100 lbs. These trials were made with a car weighing about 1½ tons, carrying a varying load of 12, 19, and 22 passengers during the trial run, making an average total weight of above 3 tons.

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[*] See his Paper on "The Best Pavement for Horse Railroad Tracks," in the *American Engineer*, June, 1881, page 103.

[†] See Mr. Conradi's paper *On the Cleaning of Tramway and other Rails*, read before the Society of Engineers, April 10, 1893.

To determine the tractional resistance of cars on rails cleaned by his apparatus, Mr. Conradi fitted it to two cars in ordinary condition and in ordinary service. The first car was started with the cleaner lowered and in action on the rails. Ten minutes later, the second car followed with a varying load of passengers up to 28 in number, also having the cleaner in action. This car started with an initial resistance of from 50 lbs. to 60 lbs. on the straight and level, and a running resistance of from 35 lbs. to 45 lbs.; on curves and at passing places, on the level, from 50 lbs. to 60 lbs.; on curves on steep gradients from 70 lbs. to 80 lbs.

It thus appeared that, on rails previously cleaned by the first car, the tractional resistance of the second car, including that of the cleaner, was less by from 25 lbs. to 35 lbs.

Assuming the average gross weight of the second car with passengers to have been 3 tons, the tractive resistances were as follows:—

Muddy and dirty, straight and level line, on starting	27 to 30 lbs. per ton
Muddy and dirty, straight and level line, running	20 ,, 23 ,, ,,
Same line, straight and level; car fitted with Mr. Conradi's cleaner in action . . .	12 ,, 15 ,, ,,

The mean running resistance with the rail-cleaner in action is thus shown to be only 63 per cent. or less than two-thirds of the resistance under ordinary conditions.

Experiments were made, in 1890, on the Mödling (Vienna)

Electric Railway, to ascertain the resistance in sharp curves, by means of a dynamometer placed between the two cars composing the train. The way consisted partly of grooved or tramway rails, and partly of Vignoles rails as used for ordinary railways. On a gradient of 1·50 per cent. or 1 in 66·6, with curves of 100 feet radius, and at a speed of 9·3 miles per hour, the resistance (irrespective of that due to the gradient) was from 17·6 lbs. to 22 lbs. per ton, averaging 19·8 lbs. of train weight on the Vignoles section, and 26·4 lbs. on the grooved section, and showing that the mean resistance on the Vignoles section was 6·6 lbs. per ton, or 25 per cent. less than on the grooved section.

PART V.

MECHANICAL POWER ON TRAMWAYS.

CHAPTER I.

HISTORICAL NOTICE OF THE APPLICATION OF STEAM POWER ON TRAMWAYS.

LATTA.—GRICE AND LONG.—TRAIN.

THE first application of steam for propelling tramway-cars, according to Mr. Cramp,* appears to have been made on the Cincinnati Tramway, in 1859, by Mr. A. B. Latta, who constructed a steam-car in which, it is said, eighty persons had been conveyed. The second application was made by Messrs. Grice and Long, of Philadelphia, who constructed a long car on two four-wheel trucks or bogies—one under each end of the car. To one of the trucks steam-power was applied by means of toothed gear. In 1860, five or six steam-cars were in use in the United States, in which the engine and boiler were placed within the car, the whole being carried on two bogie trucks. Mr. G. F. Train, in 1860, patented a steam-car, on a Bissell-truck at one end, and a pair of wheels at the other end, driven by a double-cylinder steam-engine with a vertical boiler, with intervening spur-gearing.

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* "Tramway Rolling Stock," by Mr. C. C. Cramp: *Transactions of the Society of Engineers*, 1874, page 124.

TODD.

Mr. Leonard J. Todd, of Leith, it appears, was the first steam-locomotist who, in 1871, designed an engine for tramways, specially adapted for passing through common roads and streets, avoiding noise, smoke, and steam, and possessing great facilities for starting and for stopping quickly. He insisted on the advantage of accumulating power, for which purpose he used a boiler of great capacity, holding a large quantity of water, with a very small fire-grate. "In the case of a small generator," he says,* "the only reliable way of making a furnace-boiler which can take care of itself for a considerable time is simply to give it a greater water-capacity and water-area. This water, in the most perfect and natural manner possible, acts the part of a heat-accumulator, as, during a long time, it goes on storing up heat within itself, and but very slowly raising the pressure-gauge; and, again, during a lengthened period it gives off heat from its store, while yet only slowly reducing the pressure and the water-level. Now, this invaluable action of water within a boiler is not carried to any great extent in ordinary locomotives, as there is, in them, no particular use for it, although, on undulating lines, it is well known to be of great importance that a boiler should contain a large amount of water.

"Now locomotive boilers contain 5 cubic feet of water, and 3 square feet of water-area for each square foot of grate, and never require attention oftener than, nor, indeed, so often as, every ten minutes. It is evident, then, that if we give six times as much water-capacity and water-area, while still keeping the same size of grate, as far as safety goes, we need only attend to the boiler once in sixty, instead of ten, minutes." . . . "The power required to propel a forty-four-seat car, including the weight of the propelling mechanism, with this large quantity of water, will not, on level lines, exceed ten indicator horse-power, although more than this will be required to work heavy roads. Then, small boilers and engines will give ten horse-power for each foot of grate; but we had better allow the grate of the car boiler to contain 1½ square feet; and with 30 cubic feet of water and 18 square feet of water-area—both six times the ordinary locomotive allowance—we get 45 cubic feet as the water capacity, and 27 square feet as the area at the water-level. The furnace should be of considerable depth, not less than 2 feet below the fire-doorway; so that, before commencing a run, it could be filled with fuel, and then left to sink down as it burns away."

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* *The Engineer*, July 24, 1874; page 66.

Mr. Todd constructed a steam locomotive capable of drawing two passenger cars, with a total of 76 seats, for the Tram Viâ de Santander, shown in Fig. 281. The boiler was of the locomotive form, having $3\frac{1}{2}$ square feet of area of grate, and 160 square feet of heating surface, including that of the tubes. The cylinders were $6\frac{1}{2}$ inches in diameter, with a stroke of 9 inches, and made 150 revolutions of the crank-shaft when the speed was 10 miles per hour. The driving-wheels were $5\frac{1}{2}$ feet in diameter, formed with a disc of wood. There was a bogie-truck in front, having 21-inch wheels at 3 feet between the axles. The fixed wheel-base, between the driving-axle and the centre of the truck, was 5 feet 3 inches. The motion of the crank-shaft was communicated to the driving-wheels by a pair of spur-wheels. The draught of air to the furnace was supplied from a 12-inch fan,

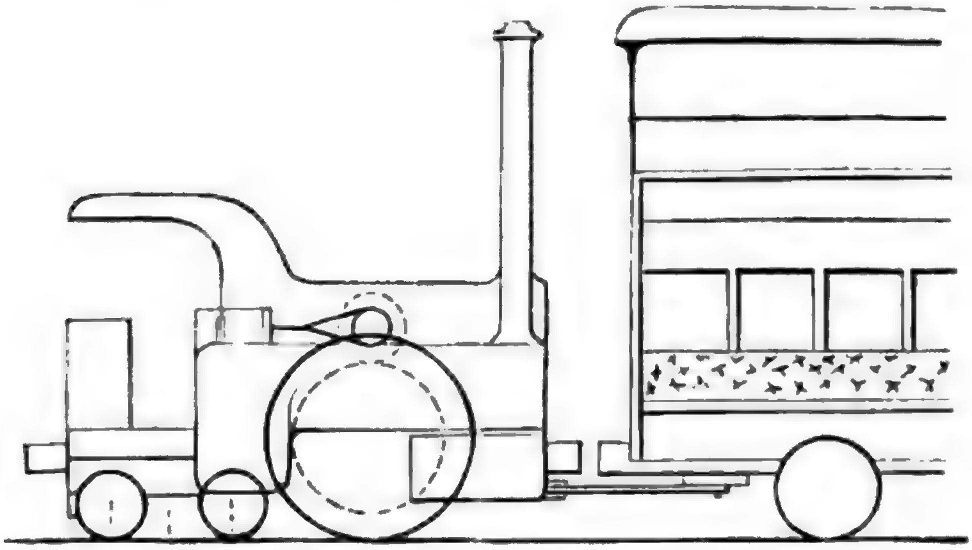
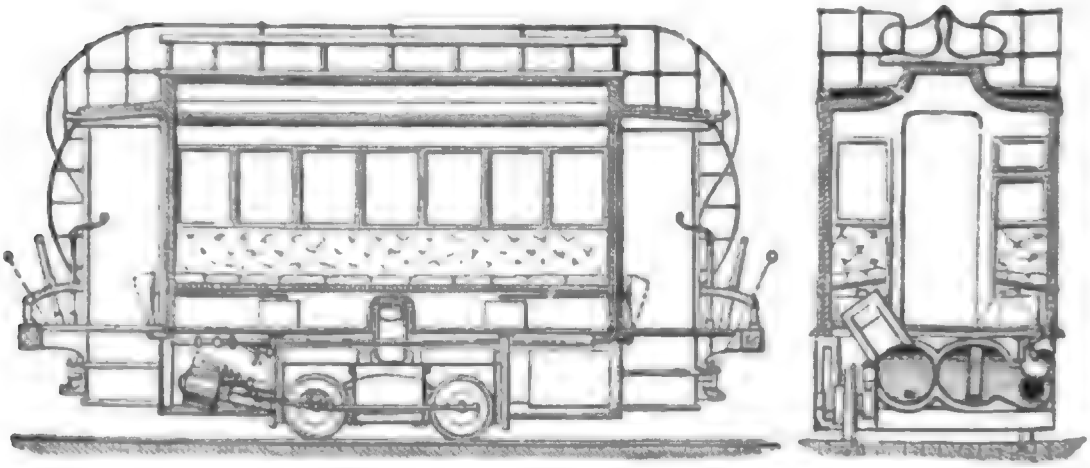


FIG. 281. Steam-locomotive, by Mr. L. J. Todd, 1871. Scale $\frac{1}{90}$.

driven by the exhaust steam of the engine, which struck the buckets of a bucket-wheel on the axle of the fan. The steam passed thence into the water tank, where condensation water might be deposited, whilst the uncondensed steam escaped into the chimney. With a pressure of steam in the boiler of 150 lbs. per square inch, the engine could exert 20 effective horse-power. The weight in working order was 5 tons. The extreme length was 14 feet 10 inches, and the width over all was 6 feet 6 inches. The chimney was 14 feet 5 inches high above the rails, to clear the awning above the cars.

Mr. L. J. Todd, early in 1875, constructed a fireless steam-car, Figs. 282, 283, in which the reservoirs and the machinery were placed beneath the floor of the car. There were two reservoirs, having the form of boilers, with domes; each reservoir containing 30 cubic feet of heated water, or a total of 60 cubic feet. The reservoirs were well coated with non-conducting material. The cylinders were 9 inches in diameter, with 8 inches of stroke, connected direct to one pair of the wheels. There were two pairs of 24-inch wheels, coupled, for adhesion, at a distance of 4 feet 6 inches apart between the axles. The cylinders are surrounded by large jackets open to the heated water, in which they are immersed; and are thus maintained at the maximum temperature in



FIGS. 282, 283. Fireless Steam-car, Mr. L. J. Todd, 1875.
Scale about $\frac{1}{96}$.

the reservoir. By this means a better action of the steam in the cylinder was expected to be effected, and the steam was superheated to some extent before it was exhausted. There was no other provision for rendering invisible the exhaust-steam, which simply emerged at the end of the car, under the roof. The body of the car was 14 feet long, and 7 feet wide over all; the extreme length over the buffers was 22 feet 6 inches. Two lines of seats were fixed on the roof; the weight of the car, in working order, was 6½ tons.

Lamm.

Dr. Emile Lamm experimented for some time, in 1871, with an ammoniacal-gas car, Fig. 284, in New Orleans. He placed a reservoir of hot water on the roof of the car, containing an interior reservoir of liquid ammoniacal gas, produced by heating sal-ammoniac in the presence of a hydrate of lime. The gas was disengaged under the influence of the heat of the surrounding water, and it passed to the cylinders, which were placed vertically at the end of the car, and were connected to a crank-shaft below, from a chain-pulley on which revolving motion was communicated by a corresponding pulley to one of the axles of the car. The gas was exhausted into the reservoir of water, where it was condensed

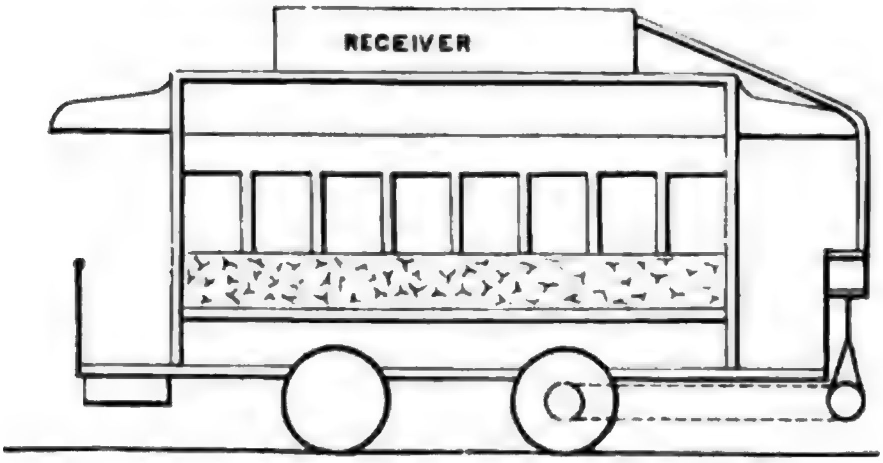


Fig. 284. Ammoniacal-gas Car, by Dr. Lamm, 1871. Scale about $\frac{1}{96}$.

and its heat was imparted to the water. This process of evolution and condensation was continued until the pressure of the gas in the interior reservoir became insufficient for keeping the pistons in motion. The greatest fall of pressure in the gas-generator during a run of seven miles, did not exceed 10 lbs. per square inch. When the water became saturated with gas, it was replaced, and the gas absorbed could be extracted from the water for further service.

The greatest difficulty in the employment of ammoniacal gas is the necessity for entirely preventing its escape into the atmosphere, to obviate the offensive smell, and the difficulty of respiration caused by its presence in the air. This objection, together with that of the chemical action of the gas on iron, led to the abandonment of the system of propulsion by ammoniacal gas, though Dr. Lamm's car was at work for some time.

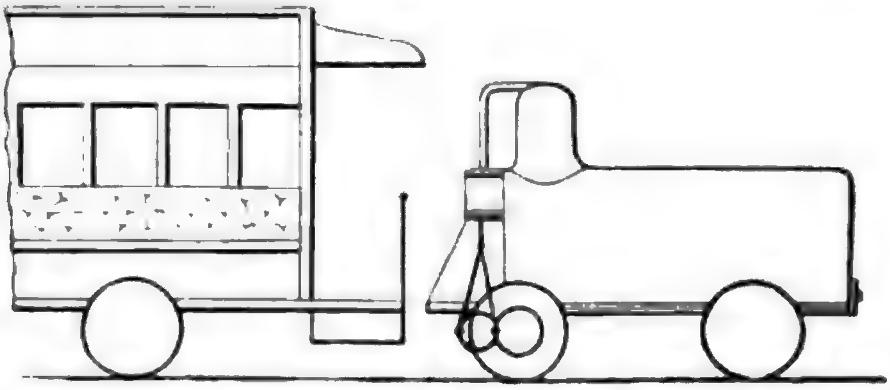


Fig. 285. Fireless Locomotive, by Dr. Lamm, 1872. Scale about $\frac{1}{96}$.

Dr. Lamm subsequently, in 1872, started a fireless locomotive—a "thermo-specific engine"—on the line of tramway between New Orleans and Carrolton. The locomotive, Fig. 285, consisted of a reservoir, about 3 feet in diameter, and 10 feet long, on four wheels, filled with water heated to a high temperature, under a corresponding high pressure. When the regulator was opened, the pressure was relieved, and steam was formed spontaneously from the water to keep up the supply, accompanied by a gradual fall of pressure. The cylinders were fixed vertically to the fore-end of the reservoir, and they worked to a crank-shaft below, from which the power was transmitted by spur-gearing to the nearest axle. The reservoir contained 60 cubic feet of heated water. It was first filled with cold water, after which a connection was made with the steam-pipe of a large stationary boiler at Carrolton, under a pressure of 200 lbs. per square inch. The cold water was quickly heated up, and raised to a pressure of 180 lbs. per square inch. The connection was then uncoupled, and the hot-water locomotive was ready for work. The exhaust-steam was discharged directly into the air, making clouds of moist white vapour. It was reported, in 1875, that the hot-water locomotives were in constant and successful operation. The tramway is about six miles in length. From the centre to the outskirts of the city, the cars are worked by mules, which are then exchanged for the engines. With one replenishment of the reservoir at Carrolton, the locomotive could make the double journey to New Orleans and back, and have a residual pressure of 50 lbs. per square inch.

By observation it was found that when the atmospheric temperature fell to 40° F., the temperature of the water, though it was 160° higher, only fell about 3° F. per hour.

EAST NEW YORK AND CANARTIO.

In October, 1873, a trial of a fireless locomotive was made between East New York and Canartio, a distance of 3½ miles. The reservoir was 3 feet 10 inches in diameter, and 10 feet long, on two pairs of 30-inch wheels, coupled. There were two steam-cylinders, 8 inches in diameter, with a stroke of 12 inches. The exhaust-steam was discharged into two condensers, one for each cylinder, fitted with 38 condensing tubes ⅝ inch in diameter, and air-pumps for creating a partial vacuum. The weight of the engine was 4 tons 3 cwt.; that of the car which was drawn by it was 7½ tons, empty, and was estimated at 12½ tons, loaded with 120 passengers. The locomotive, with the car, performed the run of 3½ miles to Canartio, on falling gradients, in 12¾ minutes, at the rate of 16½ miles per hour, whilst the pressure in the reservoir fell from

180 lbs., at the beginning of the trip, to 108 lbs. per square inch at the end of the trip. The train stopped for nine minutes at Canartio, and during this time the pressure fell to 104 lbs. The return trip, on rising gradients, was made in 17 minutes, being at the rate of 12¼ miles per hour, when the pressure fell to 45 lbs. per square inch. It is stated that the machinery of this engine was poorly designed and constructed: obviously the condenser was quite insufficient.

A few months later another fireless locomotive working on the Canartio line, was tested by Mr. R. H. Buel and Mr. H. L. Brevoort. The results of their trials were recorded in a report written by Mr. Buel, in January, 1874.* The reservoir of the locomotive was 3 feet 1 inch in diameter and 9 feet long, having a steam dome 12 inches in diameter and 2 feet high. The cylinders were vertical, 5 inches in diameter, with a stroke of 7 inches, fitted with side-valves and link-motion. The power was transmitted to one of the axles by a spur pinion of 26 teeth on the crank-shaft, gearing into a wheel of 46 teeth on the axle. There are four 30-inch wheels on two axles. The reservoir was covered with cement and felting, and the steam cylinders were heavily felted. A 2-inch pipe, perforated with small holes, lay along the reservoir, near the bottom, for nearly the whole length; and steam was admitted from a stationary boiler, through this pipe, for the purpose of heating the water.

The reservoir was half full of water at the commencement of the trip, of 4·40 miles, and the pressure of steam was 142 lbs. per square inch. The pressure of the steam during the trip was as follows:—

Time. P.M.	Pressure. lbs. per square inch.	Time. P.M.	Pressure. lbs. per square inch.
3·35	142	4·7	66
3·37	132	4·10	52
3·38	124	4·13	48
3·39	124	4·15	44
3·51	102	4·21	29
3·53	97	4·24	22
3·55	89		
4·4	70		

Average pressure 81·5 lbs.

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* Published in *The Engineer*, February 20, 1874, page 135.

The total time running the trip, 4·40 miles, was 49 minutes, of which the time actually running was 35½ minutes. The average speed whilst running was 7·44 miles per hour. The average speed of the crank-shaft was 147·4 turns per minute, giving a speed of piston 172 feet per minute. Mr. Buel calculated, from the pressures in the reservoir, that 210 lbs. of water was evaporated and consumed during the trip, or at the rate of 48 lbs. per mile run. The engine was worked in full gear, and the steam was wire-drawn by the regulator. The average initial pressure on the cylinder was found, from indicator diagrams, to be 23·52 lbs. per square inch; the average terminal pressure was 19·86 lbs.; the average back pressure was 5·15; the average effective pressure was 17·86 lbs. per square inch. The indicator power was 3·61 horse-power. Mr. Buel estimated that the quantity of steam manifested in the cylinders, according to the indicator diagrams, amounted to 147·15 lbs., or 70 per cent. of 210 lbs., the calculated quantity evaporated. The circumstances under which the steam was employed in the engine were obviously unfavourable. The steam was not worked expansively to any degree; and much of it was condensed in the cylinders. The speed of the pistons was too low, and, even with such low speed, the back pressure on the pistons amounted to 5·15 lbs. per square inch, or 22¼ per cent. of the positive pressure above the atmosphere.

BAXTER.

In 1872, Mr. Baxter, of Newark, U.S., brought out a steam-car, Fig. 286, in New York. It was placed on four 30-inch chilled wheels, at 7-feet centres, driven by a steam-engine with compound cylinders, placed together under the floor. The steam was supplied from a vertical boiler, 26 inches in diameter, and 4½ feet high. It is stated that this steam-car worked well, taking 52 passengers, ascending an incline of 1 in 13. It was also noiseless.

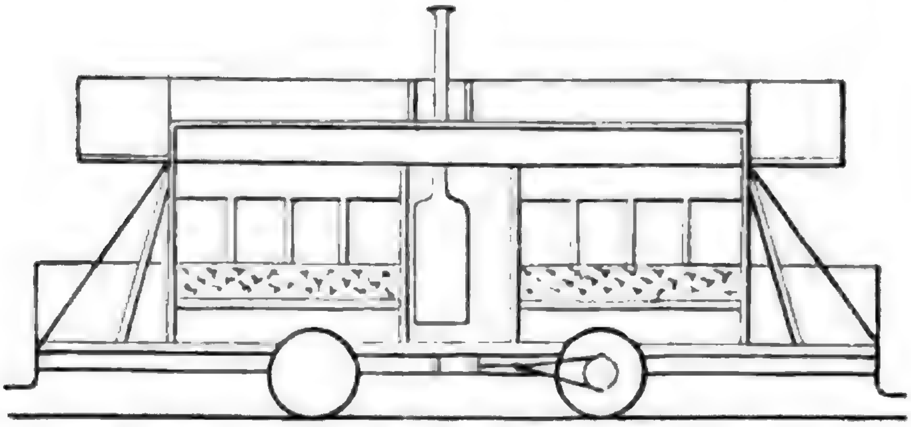

FIG. 286. Steam-car, by Mr. Baxter, 1872. Scale $\frac{1}{96}$.

GRANTHAM.

Mr. John Grantham, impressed with the need for substituting steam-power for horse-power, patented a system of steam-car in 1871, consisting of an ordinary tramway-car, in which the propelling power was to be lodged and applied at the middle of the length of the car. In 1872 he had a steam-car, Fig. 287, constructed; of which the car proper was made at the Oldbury Carriage Works, and the engines and boilers by Messrs. Merryweather & Sons, to Mr. Grantham's design. This was the first steam-car for tramways constructed in England. A boiler-chamber was constructed at each side of the body, to hold two upright boilers, leaving a central passage free for circulation in and out at

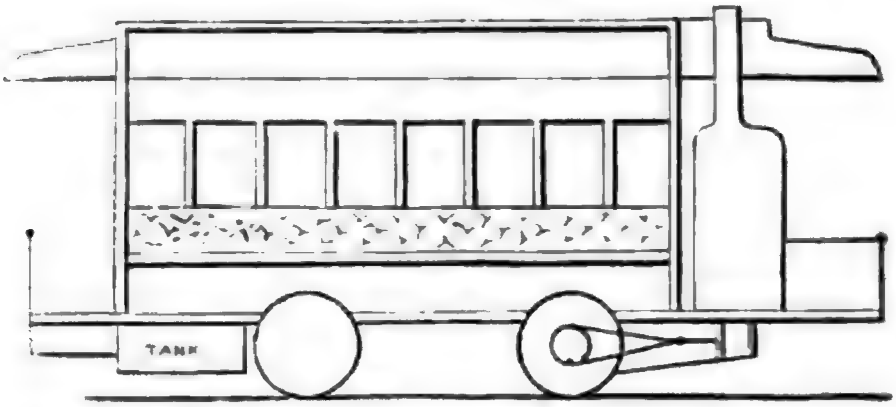

FIG. 287. Steam-car, by Mr. John Grantham, 1872.

either end of the car, or from end to end. The boilers were constructed on the Field system, with pendent water-tubes, having internal circulating tubes. They were 18 inches in diameter, and 4 feet 4 inches high; the fire-grate of each boiler was 15 inches in diameter. The machinery was placed below the floor. The steam-cylinders were 4 inches in diameter, with a stroke of 10 inches, and were connected to a single pair of driving-wheels, 30 inches in diameter. The car had four wheels, placed at 10 feet apart between the axles. One axle was for driving; the other axle had one wheel loose, on a sleeve, so that the wheels could revolve independently of each other. The car, over all, was 30 feet in length: it held seats for 44 passengers—20 inside and 24 outside. The weight, empty, was 6½ tons. Early in 1873, the steam-car was put to work experimentally on a short piece of level railway, 350 yards long, at West Brompton, where it worked for some time satisfactorily enough with steam of 90 lbs. pressure:—traversing the line at an average speed of 11 miles per hour, including the starting and the stopping. But, though a steam-car may do well on a railway, it may fail on a tramway, on which the resistance is much the greater. Thus is to be explained the failure of the Grantham car when it was tried in November, 1873, on a portion of the London Tramways, between Victoria Station and Vauxhall Bridge; possibly, also, as *The Engineer* remarked, because of difficulties in firing, due to the crowded state of the car.

The car was removed to the Wantage Tramway, where it was put to work. But it did not generate sufficient steam for working the inclines and curves of the line, which are severe. The Wantage Tramway is two miles long; the steepest gradient is 1 in 47 for 350 yards, and its quickest curve has a radius of only 75 feet. The insufficient performance of the boilers, and the danger of isolated boilers, unfitted the Grantham car, as first constructed, for employment on ordinary tramways. It was altered under the advice of Mr. Edward Woods. The boilers were taken out, and a single large vertical boiler, constructed by Messrs. Shand, Mason, & Co., with numerous small water-tubes, laid nearly horizontally, was substituted. This new boiler, like the old boilers, was placed in the middle of the car, nearer one side than the other, completely boxed off, and leaving a passage or thoroughfare towards the other side between the first-class and the second-class ends of the car. New wheels of smaller diameter, 24 inches, were substituted for the original wheels. One pair of the wheels was used for driving, and the other pair, as before, had one loose wheel to ease the passage on curves. The car was driven from either end by removable levers, by means of which the driver possesses entire control of its movements. It was 27 feet 3 inches long, 6 feet 6 inches wide, and 11 feet 1 inch high. The net weight of the car, empty, was 6½ tons, and with a supply of coke and water, 8 tons. It could accommodate 60 passengers, making a load of, say, 5 tons, and a gross weight of 13 tons loaded.

The following estimate of the cost of working tramways by the Grantham steam-car, was based on the results of experience on the Wantage Tramway. It was assumed that a mileage amounting to 26,260 miles is run during the year, equivalent to 72 miles per day, although, as a matter of fact, the daily mileage run on the Wantage line has been less than 40 miles.

WANTAGE TRAMWAY.

Estimated cost of working Grantham's Steam-car.

		£	s.	d.
One engine-driver @ 35s. per week „ stoker „ 25s. „ „ conductor „ 20s. „	80s.	208	0	0
Fuel, 7 lbs. of coke per mile for 26,260 miles = 82 tons @ 15s.		61	10	0
Oil, tallow, wash, and sundries, @ ¼d. per mile, for 26,260 miles		27	7	1
Water at 1s. per day		18	5	0
Repairs of car and machinery, at 1d. per mile, for 26,260 miles		109	8	4
Total cost		£424	10	5

or, 3·88d. per mile run.

The next steam-car constructed on Grantham's system, Fig. 288—though the leading speciality of the system nearly vanishes in the car last constructed—comprised a few further improvements, made on the recommendation of Mr. Woods. A four-wheel bogie was substituted for the independent wheels, and the boiler and machinery were placed at one end of the car. The car was constructed by the Starbuck Car and Wagon Co., Birkenhead, to work on the Vienna Tramways. The machinery and the boiler were supplied by Messrs. Shand, Mason, & Co. The boiler was one of their inclined water-tube boilers, like those which are employed by them in the construction of fire-engines. The fire-box was upright; the water-tubes, which were of small diameter, were arranged in layers, slightly inclined, which crossed each other, one layer above another. The machinery was below the platform, and the water-tanks were placed under the seats of the car. The cylinders were 6 inches in diameter, with a stroke of 9 inches; the driving-wheels were 2 feet in diameter; and the bogie-wheels were 20 inches, placed at 3 feet between the centres of the axles. The distance from the centre of the driving-axle to that of the bogie, was 8 feet. On this working base of 8 feet, there was a total length of car equal to 28½ feet, of which the length of the body was 23½ feet, comprising 14 feet for the accommodation of 24 passengers, and 9½ feet for the boiler-room. The total weight was about 7 tons gross, with passengers, of which there were 3 tons on the driving-wheels, and 4 tons on the bogie. The price of the steam-car was about £750.

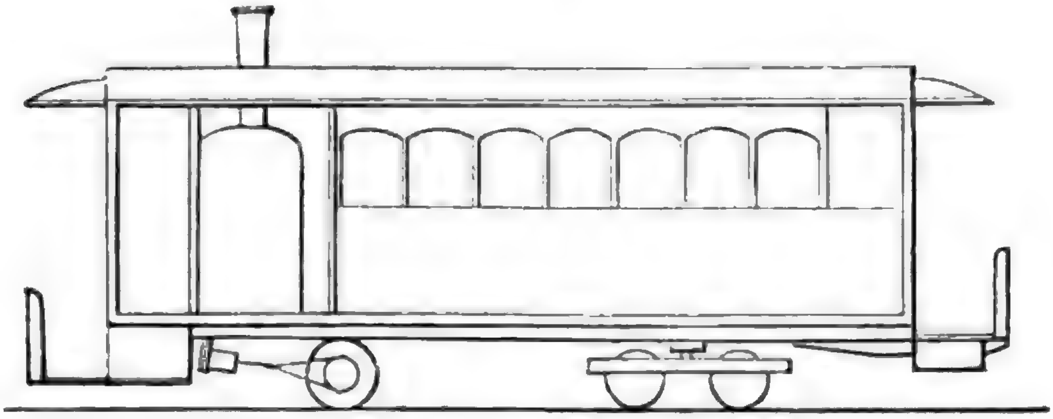

FIG. 288. Grantham Steam-car, 1876.

This car was tried on the Hoylake and Birkenhead Tramway on May 11, 1876. The tramway is 2½ miles long, with curves of 35 feet radius, and a maximum gradient of 1 in 19. The car made three complete double journeys, or a total running of 15 miles, with a load of 45 passengers. The working pressure in the boiler was 100 lbs. per square inch. The ordinary speed, whilst running, was about 10 miles per hour; but the speed, when tested, occasionally reached double that rate.

The car ascended the incline 1 in 19; but it could not have started on the incline if it had previously been stopped upon it.

A trial of this steam-car was made on reaching its destination, on the Vienna Tramways, over a piece 2·40 miles long, between the Semmering Tramway Station and the Central Cemetery, on July 28, 1876. The distance was traversed in 15 minutes, or at the rate of 9½ miles per hour, including stoppages. The steepest gradient was 1 in 48, which was ascended at a speed of 14 miles per hour. The boiler, though a rapid generator of steam, was, for the purpose of a tramway motor, too limited in water-room; and it demanded skilled management to maintain the pressure free from violent fluctuations.

The regular working speed was from 10 to 12 miles per hour.

In Mr. Woods' latest design of the Grantham steam-car, the distance between the centres of the driving-axle and the bogie was increased to 10 feet.

The Grantham car continued in daily work for some time, as late as in 1881, on the Wantage Tramway. In the reports of Mr. G. Stevenson, the engineer of the line, in that year, it appears that the steam-car consumed 220 lbs. of coke per day in running 8 trips of 5 miles each, or 40 miles in all: at the rate of 5½ lbs. of coke per mile run, and not 7 lbs., as was assumed for estimation. The car weighed with fuel and water 6½ tons, and took 2¾ tons of passengers; making a gross weight of 9¼ tons, for moving which the fuel was consumed at the rate of ·59 lb. per ton-gross per mile run. According to the first estimate given in page 420, the total working cost for the Grantham car was calculated at 3·88d. per mile run. It now appears from the published accounts, that the cost for locomotive power for the two years ending June 30, 1880, during which 24,280 miles were run by cars, amounted to 4·44d. per mile run by cars, comprising the cost for the heavier engines of Hughes already noticed.

PERKINS.

In 1874, a tramway locomotive was constructed on the system of Mr. Loftus Perkins, by the Yorkshire Engine Company, for the Belgian Street Railway Company, Brussels. It was worked with steam of a pressure of 500 lbs. per square inch, with compound cylinders, of which the first cylinder was single-acting, $2\frac{9}{16}$ inches in diameter, and the second cylinder was double-acting, $4\frac{3}{8}$ inches in diameter. Thence the steam was exhausted into an air-surface condenser, consisting of two assembl[illegible] of vertical $\frac{1}{2}$-inch copper tubes, one on each side of the engine, p[illegible] together 700 or 800 square feet of cooling surface. The steam was condensed by the cooling action of the atmospheric air which circulated about the outsides of the tubes. The upper ends of the tubes were closed, with the exception of a small aperture, about $\frac{1}{16}$ inch in diameter, left for the escape of residual vapour. The boiler was constructed of bent iron tubes, $2\frac{1}{4}$ inches diameter inside, and $\frac{3}{8}$ inch thick; it had been proved to a pressure of 2,500 lbs. on the square inch, or 167 atmospheres. Coke was the fuel used, and the force of draught was simply that due to the height of the chimney. The wheels were 2 feet in diameter; the axles were $2\frac{1}{2}$ inches in diameter, swelled to a diameter of $3\frac{1}{4}$ inches at the middle. The speed of the crank-shaft was reduced by toothed-wheel gearing, in the ratio of four to one; and the motion was taken off the second shaft to the wheels by coupling-rods. The weight of the locomotive was only four tons, in working order. The scantling of its parts appears generally to have been scarcely sufficient. The crank-shaft, for example, was only $1\frac{5}{8}$ inches in diameter. Mr. Cramp states, that in a preliminary trial of this engine, with its load, in the end of 1874, on the Manchester and Sheffield Railway, a speed of 15 miles per hour was attained, on gradients of from 1 in 200 to 1 in 80.

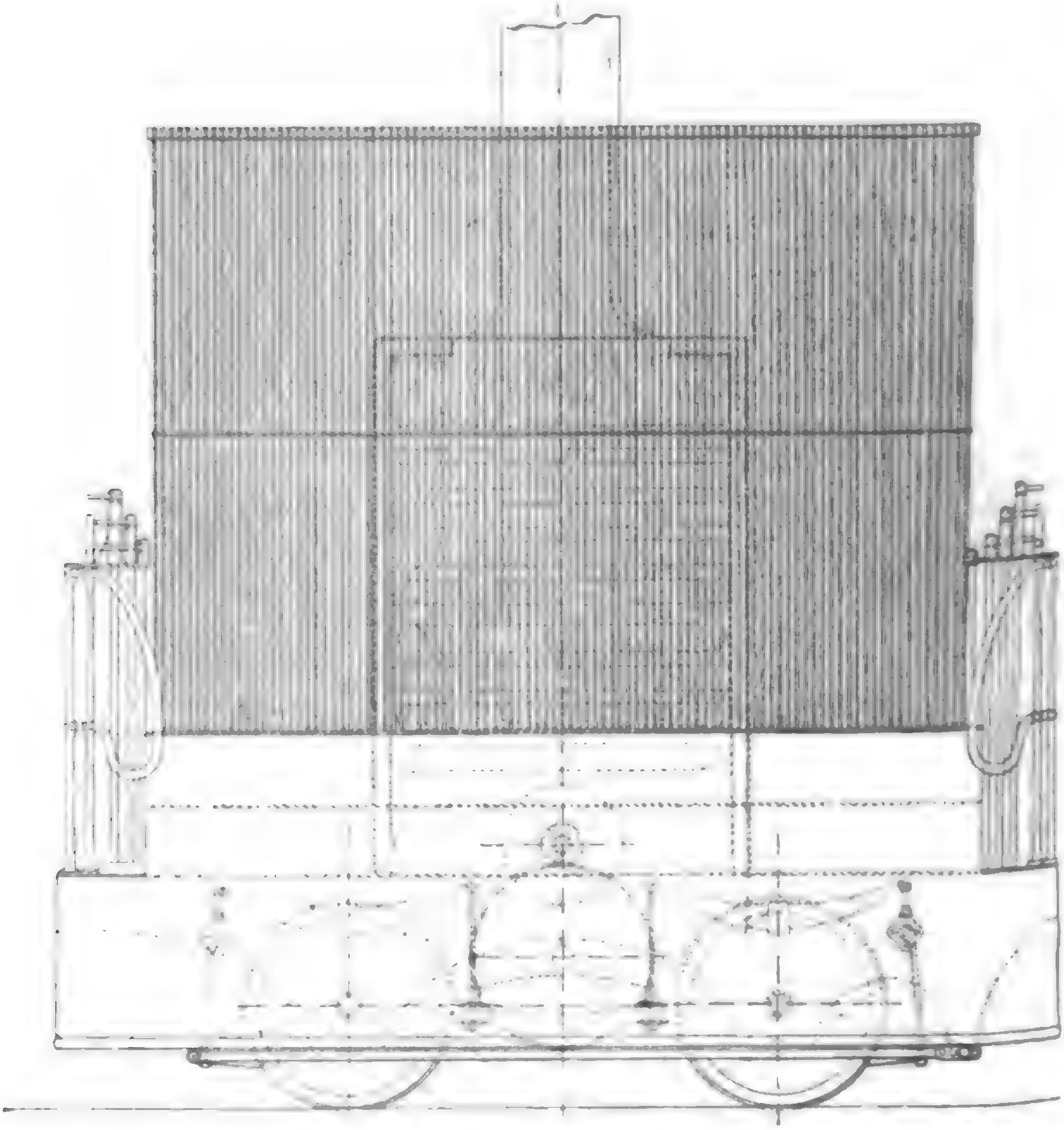

FIG. 289. Perkins's Condensing Locomotive: Elevation.

The engine was sent to Brussels, where it had the duty of drawing a one-horse passenger-car. M. Vaucamps, director of the Belgian Street Railways, writing upon the results of trials in the end of 1874, stated that the system was perfect: "In fact, no smoke, no escape of steam into the atmosphere, no noise, no feeding of water during the trip, nor even, if needful, for several days."

M. Spée, writing in December, 1875,* did not form quite so favourable an estimate; but "he was convinced that this motor, slightly modified, would answer perfectly. It would be neces-

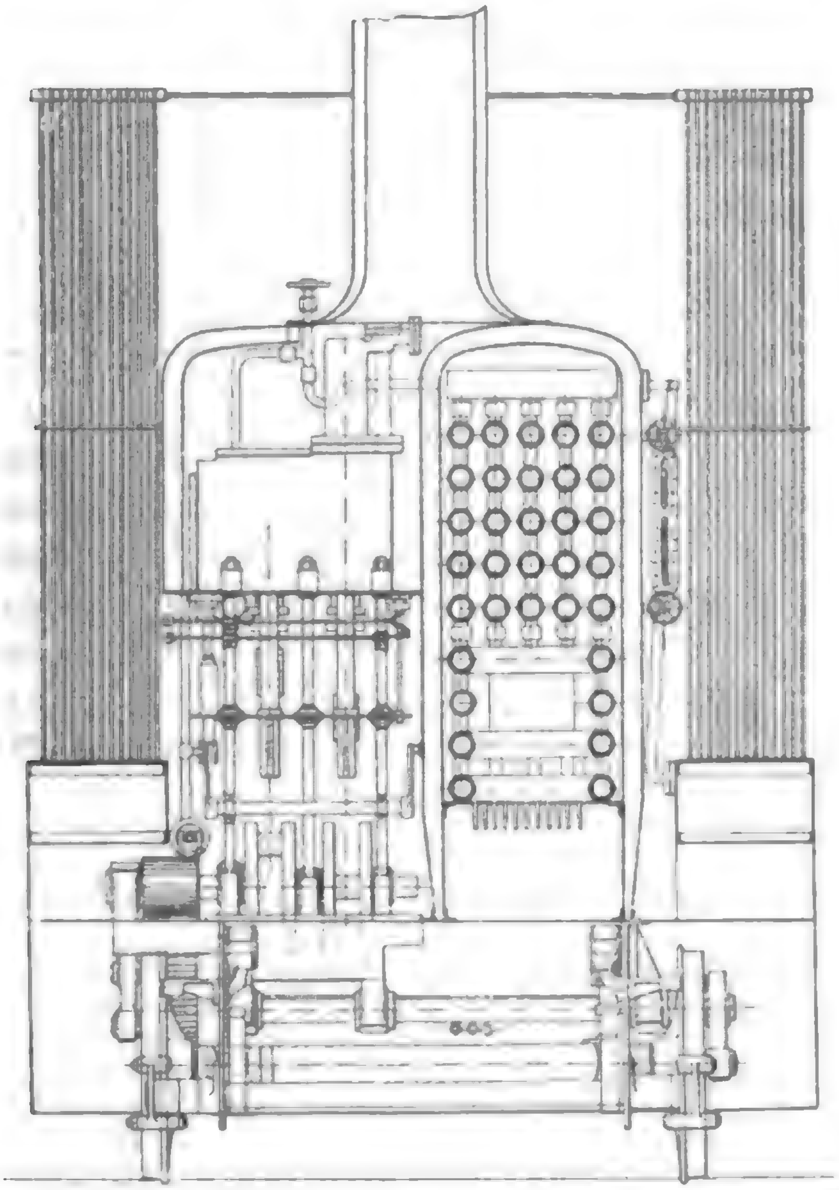

FIG. 290. Perkins's Condensing Locomotive: Transverse Section.

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* *Exploitation des Chemins de Fers Américains par Traction Mécanique*, page 12.

sary to employ two cylinders at least [probably he meant two systems of compound cylinders]. The pressure, 35 atmospheres, in consequence of which it is very difficult to maintain the joints, would not appear to be indispensable. The condenser," he added, "does not act efficiently, for the outer ranges of tubes, screening the others, prevent their being sufficiently cooled." M. Vaucamps appears to have afterwards adopted similar views, for, in 1875, he adapted two systems of compound cylinders to the engine, with a mode of coupling by frictional gearing, heavy and complicated, for moving the locomotive either way; this gearing gave rise to violent shocks.

"After having tried this coupling-gear for some time," says M. Spée, "M. Vaucamps resolved to take the machine to pieces, and sell it as old metal."

Mr. Perkins availed himself of the results of his experience with the locomotive at Brussels, in the designing of the condensing locomotive, Figs. 289 and 290. It is compactly arranged, within a length of 10 feet, a width of 7 feet, and a height of 9 feet 8 inches above the level of the rails, exclusive of the chimney, which is about 13 or 14 feet high. The wheel-base is 4 feet 3 inches in length, and the width of gauge is 4 feet 8½ inches. The boiler and the engines are placed side by side in the middle, and they are flanked by two air-condensers.

The motion is reduced by toothed gearing from the crank-shaft to an intermediate shaft, and is thence communicated to all the wheels by coupling-rods.

The boiler is vertical, and is constructed on Mr. Perkins's water-tube system. There are nine tiers of wrought-iron tubes, bent to an oblong form, with circular ends, 2¼ inches in bore, and ⅜ inch thick. The tiers are connected vertically by short junction tubes of smaller diameter. The boiler is "absolutely safe from explosion." The total external heating surface presented is 90 square feet. The area of grate-surface is 3 square feet. Thus the ratio of the fire-grate area to the heating surface is 1 to 30. The pressure of steam in the boiler is 500 lbs. per square inch, though the boiler is constructed to bear a maximum pressure of 800 lbs.

per square inch. The chimney is sufficient, by the natural draught, for the production of steam, with coke as fuel.

The engine consists of two single-acting cylinders and one double-acting cylinder. The single-acting cylinders have one piston-rod ; the steam, at 400 lbs. pressure, being admitted above the piston by the first and smallest cylinder, 3⅛ inches in diameter; then expanded into the second, or medium, cylinder, 5½ inches in diameter, below its piston ; lastly, exhausted into the double-acting cylinder, which is 7½ inches in diameter. The first and second cylinders thus work together as one cylinder, and they, with the third cylinder, are connected to a crank-shaft, with a stroke of 9 inches. The object of the combination of the first and second cylinders, and working them by single action, is to prevent the exposure of the packing round the piston-rod to the extreme temperature of the steam as first admitted.

The steam is cut off in the first cylinder at three-fourths of the stroke ; and whilst its initial temperature at 400 lbs. effective pressure is about 450° F., the pressure falls by expansion to something less than 300 lbs. effective pressure when the steam enters the second cylinder, where the initial temperature does not exceed 420° F.

A sufficiently high degree of expansion is obtained by this combination, for the working volumes of the cylinders are as follows :—

			Area of piston.	
1st cylinder		. . . .	7·67,	as 1
2nd	,,	. . . .	23·76,	as 3·23
3rd	,,	44·18 sq. in. × 2 =	88·36,	as 11·52

Setting off the expansion in the first cylinder against the reduction of expansive action by clearances, it may be taken that the steam may be finally expanded to twelve times its initial volume before being exhausted into the condensers. The cylinders are jacketed with steam direct from the boiler; the jackets are in reality coils of pipes, of small bore, conducted round the cylinders, embedded in the castings.

The engine, boiler, and chimney are entirely enveloped in a non-conducting casing of vegetable-black, 3 inches thick.

The condensers consist each of a great number of brass tubes, ½ inch in diameter outside, and 6 feet long, placed vertically on a hollow base, and pitched at a distance of one inch between centres. The steam is exhausted into the hollow base of each condenser, whence it freely enters the tubes, which are nearly closed at the upper ends, leaving only a very small opening, $\frac{1}{16}$ inch in diameter, to the atmosphere. They present an area of external surface equal to 1·500 square feet, of which, it is stated, 150 square feet are sufficient for the formation of one cubic foot of water per hour, by the condensation of steam as from a temperature of 212° F., or atmospheric pressure. The total quantity of steam that could be condensed per hour, as from 212° F., would thus amount to 10 cubic feet of water, which affords ample margin. The feed is drawn from the condensation-water. The temperature of condensation is from 210° to 212° after the water-supply is heated. The back pressure in the condenser is about 1½ lbs. per square inch above the atmosphere.

The intermediate shaft is geared to the crank-shaft in the ratio of 4 to 1, to make one turn for four of the crank-shaft, and the motion is transmitted by 4-inch cranks, with coupling-rods, to the wheels, which are 24 inches in diameter. The play of the springs is allowed for by a slot in each coupling-rod. The axle-boxes of each pair of wheels are united into one piece, reaching across the engine.

The weight of the locomotive, empty, is 5½ tons, of which 10 cwt. is contributed by the condensers. The weight, in full working order, with fuel and water for the day's work, is 6 tons.

It was anticipated that very economical results of performance would be obtained by the use of this locomotive. In a stationary engine and boiler constructed on the same system, 18-indicator horse-power has been realised with a consumption of 30 pounds of coke per hour, equivalent to 1·67 pounds per horse-power per hour. The waste of water in the engine is only 5 gallons in 12 hours.

The tramway locomotive, working at full power, indicated, it was stated, 30 horse-power, with a consumption of about 50 lbs. of coke per hour, or 17 lbs. per square foot of grate per hour.

SOCIÉTÉ MÉTALLURGIQUE.

The Société Métallurgique et Charbonnière, Belgium, according to M. Spée, constructed, in 1875, a locomotive fitted with a three-cylinder engine on Brotherhood's system.

The high speed of the engine was, in the first design, reduced by means of an endless-screw and wheel, with a view to the prevention of noise. But this gearing broke down several times, and the friction and the wear were found to be so considerable, that in a second design the reduction of speed was effected by means of spur-gear. From cranks on the last shaft of the motion, the wheels were turned by connecting-rods. A fly-wheel, also, was fixed on the first shaft of the engine, for the purpose of preventing the noise of the gearing. The locomotive resembled, in external appearance, an omnibus; the body was 7 feet 2 inches long, and 6 feet 8 inches wide; the total length of the frame was 11½ feet. There were four wheels, coupled, of which the axles were 3 feet 7 inches apart between centres. The boiler was of the Belleville type, "inexplodable," consisting of water-tubes arranged for rapid evaporation, with only the natural draught of the chimney. It is fed automatically by a donkey-engine.

The steam was slightly superheated, and was exhausted into a surface-condenser, whence the remaining uncondensed steam mixed with the air is discharged into the chimney. The principle of the condenser consisted in the division of the exhaust-steam into a number of jets, which drew, each by a conical nozzle, currents of air to condense the steam. The locomotive weighed 6 tons, and it carried a supply of coke and water for 4 or 5 miles. It was found that the condensation was imperfectly effected when the atmosphere was not warm or dry, and in another locomotive of the same kind, constructed subsequently, the area of the condensing surface was extended to five times that of the surface in the first engine.

To facilitate the lubrication of the cylinders, they were placed horizontally on the platform near the conductor. The stoker, who took his place within the covering, attended to the fire and the water.

KOHL.

In August, 1875, a tramway-locomotive, constructed by Mr. A. Kohl, a Danish engineer, was tried in Copenhagen, on the tramway worked by the American Omnibus Company. It weighed, in working order, upwards of 5 tons, and it drew two American tramway-cars filled with passengers.

SMITH & MYGIND.

In December, 1875, a tramway-locomotive, constructed by Messrs. Smith & Mygind, of Copenhagen, was put to work on the tramways of Copenhagen, drawing passenger-cars. The boiler, according to M. Spée, was of the locomotive type, and compound cylinders were employed. The exhaust steam was condensed in a surface-condenser, holding a quantity of water sufficient to last an hour.

BÈDE.

MM. Bède & Co., Belgium, constructed a fireless steam car, in 1875, to the directions of the Société Générale de Tramways. The reservoirs consisted of four small horizontal cylinders placed under the seats, and two upright cylinders placed one on each side of the car, enclosed, and leaving a passage-way within the car between the first-class and second-class compartments. The steam, disengaged in the upper part of the upright cylinders, descended in a pipe through the hot water, to the steam cylinders. There were three steam cylinders, 4½ inches in diameter, with a stroke of 14·2 inches, connected to a triple-crank axle, with 28-inch wheels. They were fitted with link-motions. The crank-axle was placed under the middle of the car, which originally had two other axles with 20-inch wheels which were loose on the axles. One of the pair of wheels was removed, and the wheels of the other pair were fixed on the axle. But the wheels were not coupled. The reservoir contained 50 cubic feet of water heated to 365° F., for an effective air-pressure of 10 atmospheres or 162 lbs. per square inch. The reserve of heat was sufficient to last 50 minutes at the ordinary speed on tramways, with a load of 1·60 tons. The car ran with facility on curves of 40 feet radius, and ascended an incline of 1 in 28, with a pressure of 4½ atmospheres, or 66 lbs. per square inch. The car stopped and started quickly and without shock. The exhaust-steam was discharged into a chamber so arranged as to separate water from the steam, and the sound of the escaping steam was scarcely audible.*

It appeared that this engine worked daily with regularity and success in Belgium.† The charging of the reservoir was renewed every two hours, and was done in a quarter of an hour. The cylinders constituting the reservoir were covered with woven glass and lagging. A tank was filled with cold water for condensing the exhaust steam; there were, it is said, four horizontal steam-cylinders, two at each end, all of which are brought into action in ascending the steepest incline already noted. The speed attained was ten miles per hour, on a level. Suet was used for lubrication, to obviate the odour of oil. The sockets for the driving and other levers were in duplicate, one set at each end of the car. The engine was about (September, 1877) to undergo a few alterations, but it was ultimately taken off the line on account of the excessive cost of working.

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* These particulars are borrowed from M. Spée.

† *The Foreman Engineer and Draughtsman*, September, 1877, page 138.

BALDWIN.

Reverting to America, a steam-car was built at the Baldwin Locomotive Works, in 1875, and was experimentally worked on the Atlantic Avenue Railway (Tramway) at Brooklyn, for the first six months of 1876. It was run and kept in order by one engineer during that time, consuming from 7 lbs. to 8 lbs. of coal per mile run. Night and morning, it drew behind it an additional car with passengers from and to New York. On several occasions a speed of 16 or 18 miles per hour was attained with it. In June, 1876, the steam-car was removed to Philadelphia, where it was worked on the Market Street line till nearly the date of closing the Centennial Exhibition. The car was constructed with steam-cylinders under the body, connected to a cranked axle, to which the fore-wheels were coupled. The hind-wheels were free. The machinery was fixed to an iron bed-plate bolted to the wooden framing of the car. This mode of construction was found to be objectionable, as the framing was not strong enough for the purpose, and the crank-axle was subject to occasional breakage.

In the end of 1876, therefore, the steam-car was removed to the works of the Baldwin Company to be reconstructed. An iron framework was made, on which an upright boiler and the machinery were fixed, independent of the body of the car, which was bolted down to it; and outside horizontal cylinders were employed. In this way existing car stock could be utilised—bolting down the bodies to an engine-frame adapted to receive them and carry them. The throttle-valve was placed close to the cylinders—a good idea—having the advantage of promptly stopping and starting the engine. The car was carried on rubber springs, with cross equalising-beams; the motion was smooth, free from interference by the action of the machinery. The boiler was of steel, double-riveted, and was calculated to support with safety a steam-pressure of 300 lbs. per square inch. But a pressure of 90 lbs. was sufficient to move the loaded car over the steepest inclines on the Market Street line, which are about 1 in 22, without ever "stalling" or requiring assistance. The reconstructed steam-car, which was named the "Baldwin," was replaced on the Market Street Tramway on March 21, 1877; it worked regularly for four weeks, to April 18:—running 88 miles per day, seven days in the week.

The quantity of fuel, coal, consumed by the steam-car amounted to 4,950 lbs. in seven days, running (7 × 88 =) 616 miles:—at the rate of 8·03 lbs. per mile. The car did not require any repair during the four weeks' run. The actual daily expenses, with estimated cost for maintenance and interest, were as follows:—

BALDWIN STEAM CAR.

Cost of Running one Steam-Car one day.

	Dollars.		s.	d.
Fuel, 88 miles, at 8 lbs. per mile, equal to 704 lbs., @ 4 dollars per ton	1·26	or	5	3
Oil, waste, and tallow	·25	,,	1	0½
Wages of engineers, 16 hours @ 25 cents .	4·00	,,	16	8
Repair and maintenance of car and machinery	1·00	,,	4	2
Working cost . . .	6·51	,,	27	1½
Daily interest on cost of steam-car, 3,000 dollars, or £625 @ 6 per cent., per year .	·49	,,	2	0½
Total cost per day (4d. per mile run)	7·00	,,	29	2

The Baldwin Company also constructed a tramway locomotive, having boilers and cylinders of the same capacity as those of the steam-car, on an iron frame; of which, with water-tanks, the total weight was 12,000 lbs., or 5·35 tons. The whole of these masses were carried within the wheel-base, so preventing rocking and pitching. A locomotive of this class was constructed in 1876 for the Citizens' Railway of Baltimore, of which the maximum gradients are 1 in 14·3. It was capable of drawing one car up the incline, but it had not sufficient power to take up two cars. A second engine, weighing about 7·2 tons, was built and delivered in December, 1876. During severe snow-storms it ascended the maximum incline, drawing one car, with 100 passengers, when the tracks were covered in places with a mixture of snow and d[illegible] a depth of 8 or 10 inches. It could, without difficulty, draw a loaded car, for taking which, otherwise, four horses were required. In better weather the locomotive worked regularly—taking two cars up the incline.

The following is a statement, for comparison, of the cost of running horse cars, based on the reports of various tramway companies in Philadelphia:—

HORSE CARS IN PHILADELPHIA.

Cost of Running one Two-Horse Car one day.

	£	s.	d.
First cost of one car, 1,000 dollars, or	258	6	8
Ditto 9 horses, @ 140 dollars, or £29 3s. 4d.	262	10	0

	s.	d.
Feed and stable expenses (feed, straw, hostlers, stable boss, medicines), of 9 horses, @ 46 cents, or 1s. 11d.	17	3
Shoeing of 9 horses, @ 6 cents, or 3d.	2	3
Maintenance of harness of 9 horses, @ 2 cents, or 1d.	0	9
Maintenance of 9 horses, @ 33⅓ per cent. per year, for depreciation, equivalent per day for 9 horses to . .	4	9½
Maintenance of car	1	8
Wages of driver	7	3½
Daily interest on cost of car and 9 horses, @ 6 per cent. per year	1	6½
Total . . .	35	6½

Compared with this amount, the cost of running a steam car, before estimated at 29s. 2d. per day, shows a difference of 6s. 4½d. per day, or 18 per cent., in reduction on the cost for horse-power.

RANSOM.

Mr. Louis Ransom's steam car is so constructed that the machinery may be readily adapted to existing cars. A double-crank axle with driving-wheels for inside cylinders, is substituted for one pair of ordinary wheels, and the machinery is placed horizontally under the floor. The two cylinders are cast in one piece, connected to the driving axle by means of three bars, which have bearings on the axle, and form the framing of the engine.

The valve-gear consists of a rocking expansion-link, vibrating on a pivot at the middle, and worked by two eccentrics. The valve-spindle is connected to the expansion-link by a radius-link, which is shifted vertically for reversing and for varying the degree of expansion. The forward end of the engine-frame, at the cylinders, is supported by a loop pinned to the bottom of the body. By this arrangement the engine is suspended on three points, and is easily removed for the purpose of repair. Light repairs may be made by merely detaching the fore-end of the frame from the body, and letting it hang from the crank-axle. The machinery is accessible for general purposes through trap-doors in the floor. It is enclosed in a casing made so perfectly dust-tight that even after having run all day through dusty streets the engine is free from dust, and is actually covered with drops of water, being the slight quantity of steam condensed which escapes from the stuffing-boxes. The boiler is placed a little forward of the front axle; the water-tank is under the floor at the rear end; the body—for passengers—is nearly equally divided forward and aft of the hind axle. To quell the noise of the exhaust-steam, the steam is passed through a muffler, consisting of a box filled with balls or pebbles.

The body of the car is 16 feet long, having seats for 22 passengers. The length of wheel-base is 7 feet—longer than what is customary, but the car runs by so much the more steadily. It is said that there is less *teter* in passing over rough or uneven places in the line, although the resistance on curves is greater than with a shorter base. The cylinders are 5½ inches in diameter, with a stroke of 14 inches. The boiler is upright, 3 feet 1 inch in diameter, and 4 feet 8 inches high, made of one sheet of No. 1 charcoal hammered iron; it contains 300 upright flue-tubes, 1½ inches in diameter, and 12 inches long, making up a heating surface of 116 square feet, for a grate-area of 6½ square feet. The pressure in the boiler is 120 lbs. per square inch; the testing pressure was 200 lbs. The steam-room has 26 times the capacity of one cylinder of the engine. The car is fitted with a steam brake, having a cylinder 3½ inches in diameter, with a stroke of 8 inches: the piston-rod is extended with a rack, gearing into a toothed sector linked to knuckle-jointed levers, by which the brake-blocks are forced against the inner edges of the wheels. The steam-valve for the brake is thrown open by the same movement which closes the regulator.

In January, 1876, one of the Ransom steam cars, constructed by Messrs. Gilbert, Bush & Co., Troy, N.Y., was placed on the Coney Island Railroad, 4½ miles in length, where it ran 81 miles per day for five months. The double trip of nine miles was made in 40 minutes, at a gross average speed of 13½ miles per hour. After each double trip, the steam-car was at rest for 50 minutes. The quantity of coal consumed per day, as fuel, amounted to 600 lbs. per day; equivalent to 7·4 lbs. per mile run. The total cost for running 81 miles per day was estimated at 8·31 dollars, or 34s. 7½d. per day—at the rate of 5·13 pence per mile run. The engine was sold, and went to work on the Onondaga Valley Road, Syracuse, N.Y.

Six Ransom steam cars were placed on the Market Street line, Philadelphia, on March 21, 1877, to work on the Baring Street branch, on which the maximum inclines are at the rate of 1 in 22, with many curves. Though seated for 20 passengers, these cars have frequently carried 50 passengers. Some difficulties have been encountered in running the cars, which appear to have been scarcely able to cope with the gradients and curves of the Baring Street branch. In Mr. Ransom's opinion, the engine should have had 7-inch cylinders for this traffic. Besides, the "peculiar greasy mud" of the city causes the ordinary chilled cast-iron driving-wheels to slip, a defect which Mr. Ransom proposed to remedy by the substitution of tyres of steel for the driving-wheels.*

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* The above particulars of the performances of the Baldwin steam car and the Ransom steam car are drawn from the reports of the Secretary of the Franklin Institute upon "Steam on Street Railways," published in *The Journal of the Franklin Institute*, June and July, 1877.

CHAPTER II.

CURRENT PRACTICE IN THE EMPLOYMENT OF STEAM POWER.

MERRYWEATHER.

MESSRS. **MERRYWEATHER** & SONS were early engaged in the design and manufacture of tramway-engines. It has already been noted that this firm constructed the machinery for the first steam-car made for tramways in England, in 1872, to the designs of Mr. Grantham. They secured their first patent for tramway-engines of their own design in April, 1875. The first engines on this system constructed by them, were to the order of Mr. G. P. Harding, for working the line of tramways in aris, 4½ miles long, between the Bastille and the Mont Parnasse railway station. The first of these was started about the month of November, 1875, and in January, 1878, thirty-six of Messrs. Merryweather's engines were regularly at work on that line. There were also ten of their engines on the line from the Bastille to St. Mandé. Many improvements, naturally, have been made in the design and construction of the engines. In the earliest engines, a portion of the exhaust-steam was discharged into the ash-pan and passed through the fire, that it might be superheated, and, mixing with the remaining portion discharged direct into the chimney, reduce the visibility of the escaping steam.

In their later designs, Messrs. Merryweather disposed of the exhaust-steam by means of an "auto-absorbing" apparatus—a simple arrangement in which the steam was condensed by cold water.

Messrs. Merryweather & Sons construct three classes of steam locomotives for tramways :—

1. Cylinders, 6 inches diameter; stroke, 9 inches; wheels, 2 feet. Weight, empty, 3¼ tons; in working order, 4 tons.

2. Cylinders, 7 inches diameter; stroke, 11 inches; wheels, 2 feet. Weight, empty, 5·4 tons; in working order, 6 to 6½ tons.

3. Cylinders, 7½ inches diameter; stroke, 12 inches; wheels, 2 feet. Weight, empty, 6½ tons; in working order, 7½ to 8 tons.

The working pressure in the boiler is 8 atmospheres, or nominally 120 lbs. per square inch. The guaranteed maximum performances are respectively as follows :—

1. To draw 1 loaded car, weighing 7 tons, up an incline of 1 in 30.

2. To draw 1 loaded car, weighing 7 tons, up an incline of 1 in 18; or 2 loaded cars, weighing 14 tons, up an incline of 1 in 30.

3. To draw 2 loaded cars, weighing 14 tons, up an incline of 1 in 16; or 3 loaded cars, weighing 21 tons, up an incline of 1 in 20.

Engines of the third class have taken three cars up an incline of 1 in 18, at regular work.

The tramway locomotives of Messrs. Merryweather & Sons, worked on the Southern Tramways of Paris, thirty-six in number, had, as already mentioned, two cylinders, 6 inches in diameter, with a stroke of 9 inches. The cylinders are horizontal, inside the framing, and connected to cranks on the driving-axle. There are two pairs of driving-wheels of cast steel, coupled, 2 feet in diameter, 4 feet 7 inches apart between centres of axles. The blast-orifice is annular in form, and has an area of 1 square inch, being about 1-28th of the area of the pistons. The length of the frame is about 8 feet, and the width is 6 feet. Over the buffers, which are central, the extreme length is about 8 feet 10 inches. The load is carried by a pair of helical springs over each journal. The buffing and draw-springs, of india-rubber, at each end, are well connected to the frame, the attachment having been taken as near to the centre of the machine as was conveniently practicable. A close-laid draw-pin eases the traction very much, compared with a distant draw-pin. The engine is braked by cast-iron blocks, applied one to each wheel. The whole machine is enclosed in a large wooden box, made like a short tramway-car, having several windows. The fire-box is 2 feet wide, and 1 foot 6 inches long. The barrel of the boiler is 2 feet 9 inches long, and 2 feet 3 inches in diameter; it contains 65 flue-tubes, 1¾ inches in diameter, and 3 feet long:—

	Square feet.
Heating surface in fire-box	16·0
Do. do. tubes	89·3
Total	105·3
Area of fire-grate	3

Ratio of grate to heating surface, 1 to 35.

The pressure in the boiler is nominally 8 atmospheres, or 120 lbs. per square inch; but the working pressure usually maintained is 6 atmospheres, or 90 lbs. per square inch. The steam is cut off in the cylinders at from 1-4th to 3-4ths of the stroke. The length of the journey is 4 miles, between the Bastille and the Gare de Mont Parnasse, on which the maximum incline has a gradient of 1 in 50, whilst there are long inclines of from 1 in 60 to 1 in 70. The speed is limited by law to 9 kilometres, or a little over 5½ miles per hour; but it occasionally rises to 14 or 15 miles per hour, and the average speed, including stoppages, is 8½ miles per hour. The weight of the engine, empty, is 3¼ tons; with coke and water, 4 tons. It draws a car which, when loaded, weighs 7 tons; and it can ascend the inclines with its load, and keep time, with a pressure in the boiler of 90 lbs. per square inch. The fuel (coke) consumed per day, amounts to 550 lbs. for a total distance run of 100 miles:—at the rate of 5½ lbs. per mile. The combustion of the fuel proceeds at a comparatively low rate. Supposing that the average actual speed while running is 10 miles per hour, the quantity of coke consumed per hour would be (10 × 5·5 =) 55 lbs., equivalent to (55 ÷ 3 =) 18⅓ lbs. per square foot of grate. In the ordinary practice of locomotives on railways, the quantity of fuel consumed per square foot of grate per hour amounts to three or four times as much. The comparatively low rate in the Merryweather engine is easily accounted for by the comparatively low speed, and the reduced blast and draught which are required for the generation of steam. It is true, the area of the blast-orifice is contracted to 1-28th of that of the pistons, which is a very small fraction, and would cause great back-pressure on the pistons if the engine travelled at a high speed. But it is to be observed that the pistons travel at a comparatively low speed. The wheels, 2 feet in diameter, and 6·28 feet in circumference, make (5,280 ÷ 6·28 =) 841 turns in a mile, or in (60 ÷ 10 =) six minutes of time, when the speed is ten miles per hour. The number of turns per minute is, then (841 ÷ 6 =) 140; and, as the double stroke of the piston is (9 × 2 =) 18 inches, or 1·5 feet, the speed of the pistons is only (140 × 1·5 =) 210 feet per minute.

The engines, more recently constructed, for the tramway from the Bastille to St. Mandé, are more powerful than those just described. They have 7-inch cylinders, with a stroke of 11 inches, and 2-feet wheels. The fire-box is 2 feet 2 inches by 2 feet, having an area of 4·33 square feet of grate. The fire-box surface is 24·5 square feet; there are 79 flue-tubes, 1¾ inches in diameter outside, and 3 feet 6 inches long, giving 126·6 square feet of heating surface. The total heating surface is 151·1 square feet, and it amounts to 35 times the area of grate. The diameter of the barrel of the boiler is 2 feet 6 inches; the length of the engine, over all, is 6 feet 7 inches, and the length of the wheel-base is 4 feet 6 inches.

Additional engines of equal power have been constructed for other lines of tramway in Paris.

The locomotives constructed for the tramway from Barcelona to St. Andrès, on a 1-metre gauge, have 6-inch cylinders, with a stroke of 9 inches and four 2-feet wheels, coupled. The fire-grate has 3 square feet of area. The barrel of the boiler is 27 inches in diameter; and there are 96 flue-tubes, 1⅜ inches in diameter, and 3 feet in length. The heating surface of the fire-box is 16 square feet, of the tubes 102·7 square feet, total surface 118·7 square feet.

A tank to hold a supply of cold water, 300 gallons, for condensing the steam, is placed overhead. The exhaust-steam is discharged from the cylinders into an apparatus like an ejector, in the lower part of the engine, to which the water is conducted from the tank, where it meets and condenses the exhaust steam, and whence it returns by a return-pipe to the tank. The water, of course, becomes gradually heated, but the condensation of the steam is effective, and there is no appearance of escaping steam until the temperature of the water arrives near the boiling point. Possessing so wide a range of effective action, a tankful of cold water lasts good, for condensing the exhaust-steam, for two hours, over a distance of more than 10 miles. The distance to be run before the water can be heated, from, say, 60° F. to, say, 180° F., is easily determined.

The quantity of fuel consumed per mile is 5 lbs., evaporating, say, 7 lbs. of water per lb. of fuel. The quantity of steam generated per mile would be (5 × 7 =) 35 lbs., exhausted at, say, a pressure of 3 ibs. per square inch. The total heat of 1 lb. of steam of 3 lbs. effective pressure per square inch is 1,117 units, reckoned from a temperature of 62° F., or 967 units, reckoned from 212°. The mean total heat per pound of steam to be extracted by condensation is (1117 + 967) ÷ 2 =) 1,042 units. Each pound of condensing water absorbs (180 — 62 =) 118 units of heat, when heated from 62° to 180°; and, to condense 1 lb. of steam, the quantity of water required is (1042 ÷ 118 =) 8·8 lbs. The total weight of water in the tank is (300 gallons × 10 =) 3,000 lbs.; and (3000 ÷ 8·8 =) 341 lbs. of steam, is the total quantity that may be condensed by the store of condensing water. As 35 lbs. of steam is consumed per mile, the supply of condensing water would last for (341 ÷ 35 =) 10 miles, equivalent to 30 gallons per mile—a result of calculation which agrees with the results of practice.

For occasional use, a blast-pipe is adopted for exhausting the steam into the chimney; it is fitted with the means of contracting the area of the orifice, by a conical plug with a rack-and-pinion movement. A steam-jet is also available at will, by a nozzle placed concentrically within the blast-pipe. Two truncated cones are placed one above the other, over the blast-pipe and below the chimney, through which the blast is directed upwards. They are useful in inducing the draught from the lower rows of flue-tubes, as well as from the upper rows; and they assist the absorption of the exhaust steam by the hot air, whereby, except in very cold weather, it issues from the chimney invisible; so far dispensing with the use of the water-condenser.

The Barcelona Tramway was opened in November, 1877. The engines each take two loaded cars up inclines of 1 in 30. The additional engines supplied by the same makers have cylinders 7 inches in diameter, of the same power as the later engines constructed for the Paris Tramways. They weigh, empty, 7½ tons.

The engines each run about 90 miles per day, from 5 A.M. till 9 P.M. Each train consisted of two second-class cars and one first-class car. The engine stock consists of five, having 6-inch cylinders, already described and illustrated; and five others having 7-inch cylinders with 11 inches of stroke, weighing, empty, about 7½ tons. Don Alejo Soujal, the chief director of the line, is about to construct other tramways, which, in view of the success of the Barcelona line, will be worked by steam power.

Merryweather's Latest Condensing Tramway Locomotive.—This engine is constructed for a gauge of 4 feet 8½ inches, and is fitted with two 7½-inch cylinders inside the longitudinal frame-plates. It has two pairs of 28-inch wheels, coupled, on a base 5 feet long. The cylinders are inclined to clear the coupled axle, and they are fitted with the ordinary shifting link motion, with reversing gear at each end of the engine. The boiler is of the locomotive type, of mild steel, with a copper fire-box 2 feet 3½ inches square, and 85 brass tubes 1¼ inches in diameter outside, 4 feet long. The heating surface is 181 square feet. The working pressure is 150 lbs. per square inch. The ash-pan is specially designed to prevent the dropping of cinders or the showing of fire. It can be easily cleaned out when required. The ash-pan damper can be worked from either end of the engine. The wheels are of steel, fitted with rolled steel tyres secured by screws. The exhaust steam is condensed in an air-condenser, consisting of 404 thin 1-inch copper tubes, laid in three double tiers, 5 feet 10 inches long, making 617 square feet of condensing surface, transversely over the roof. These are fastened by ferrules at each end to longitudinal copper passages or ducts, into which the exhaust steam is discharged, and from which the steam is free to pass into the transverse tubes. The ducts are divided by internal partitions into sections in order to direct the flow of steam alternately from one side to the other.

In order to fulfil the conditions laid down by the Board of Trade a centrifugal governor is employed, driven by gearing direct from the driving-axle, by the action of which the throttle-valve is closed when the speed exceeds 8 miles per hour. Should the speed increase, nevertheless, a small steam-valve opens automatically for steam to the break-cylinders, by which the break is applied. When the speed is reduced below the assigned limit the break is thrown off. The steam break can also be applied by the driver's foot on a treadle. All hand-gear is in duplicate, being at each end of the foot-plate.

The engine, empty, weighs about 8 tons, and with water and fuel about 9 tons. The engine, it is stated, can take, in ordinary working, 80 passengers on an incline of 1 in 20.

Cassel, Guernsey, and Wellington, N.Z.—The engines of the Cassel Tramway, opened in August, 1877, were supplied by Messrs. Merryweather & Sons. They were constructed with 7½-inch cylinders, having 12 inches of stroke. They draw three loaded cars and one luggage truck over the road, on which the inclines are severe; some of them equal to 1 in 16.

The Guernsey Steam Tramway, to connect the town of Guernsey with the town and harbour of St. Peter Port, and St. Sampson's, was opened in 1878. It is about 3 miles long, constructed to a gauge of 4 feet 8½ inches, having a ruling gradient of 1 in 32, with curves of which the quickest is of 50 feet radius. The line is worked by Merryweather engines, having 7-inch cylinders. Each engine on duty runs 72 miles daily; but on Saturdays 88 miles. The train consists of 2 cars, first and second class, and one luggage truck, except in the morning and evening, when one extra car is attached for workmen.

The first tramways in New Zealand were opened in February, 1878, at Wellington. The locomotives, supplied by Messrs. Merryweather & Sons, have 7-inch cylinders, with an 11-inch stroke. The gauge is 3 feet 6 inches.

MERRYWEATHER.—ROUEN TRAMWAYS.

Of the Merryweather tramway engines that were at work on the Southern Tramways of Paris, at the time of Mr. Harding's contract, in 1878, 10 engines were translated to the Rouen Tramways, the engine-stock of which lines was in 1881 as follows:—

Engines.	Cylinders.	Wheels.	Weight empty.
	Inches Inches	Feet.	Tons.
6, Merryweather & Co. . .	6 × 9	2	3⅓
4, Merryweather & Co. . .	7 × 11	2	5½
6, Fox, Walker & Co. . . .	8 × 12	2⅓	7
1, Fox, Walker & Co. (6 wheels)	7 × 10	2½	6
6, Compagnie de Fives-Lille .	7 × 11	2	5¾

All of these engines, excepting three from the Fives-Lille Company, had done service on the Southern Tramways of Paris at the time of Mr. Harding's contract. There were 17 engines on the working list, of which 13 usually were in working order, and 4 under repair.

The ruling gradient on the Rouen Tramways is 1 in 20, at one end of the line, on a very sharp curve at the commencement. There are also a long incline averaging 1 in 40, and other inclines. The average number of miles run per day per engine on duty is 56 miles. The speed is fixed at 5 miles per hour within the town, and 8 miles per hour outside. This speed is frequently exceeded. as the line is single, with passing places, and time must be kept.

The working pressure varies from 8 to 10 atmospheres, and the engines are non-condensing. The running expenses for locomotive-power per mile run (March, 1881), were as follows:—

	Pence.
Coke, 5·360 kilogrammes, or 11·8 lbs. @ 28½ francs per ton	1·53
Oil, ·087 kilogramme, or ·19 lb. @ 85 francs per 100 kilos	·73
Tallow, ·013 kilogramme, or ·0286 lb. @ 100 francs per 100 kilos	·13
Waste, water, anti-corrosive fluid, trimmings, &c.	·16
	2·55
Stores consumed for depôt and reserve engines, coke, firewood for lighting up, packing, trimmings, &c.	·36
Stores	2·91
Wages of drivers (5s. per day), firemen (3s. 4d. per day), night cleaners, and fitters, yard men and foremen	2·20
Running expenses	5·11
Repairs of engines,—wages (1·68d.) and stores (1·33d.)	3·01
Total working cost, per mile run	8·12

Mr. J. Arthur Wright, the Engineer and General Manager of the Rouen Tramways, who supplied the foregoing statement of cost, explained that the comparatively large item for repairs of engines, 3·01d. per mile run, may, by alterations he is making in some of the engines,—stiffening the framing, and enlarging the working bearings, &c.—be eventually reduced to from 1½d. to 1¾d. per mile run, which is about what the best of the Merryweather engines are costing. The total working cost for engine-power would then amount to from 6½d. to 7d. per mile run. In 1880, the cost for repairs to engines varied from 2·49d. in July, to 3·65d. in December.

Although the average mileage run by engines has been taken at 56 miles-run per day, the following for three recent months give higher averages:—

	Engine-days.		Per diem.	Miles run.	Per engine per day.
February, 1881	209	=	7·46	12,816	61·32
March ,,	224	=	7·22	15,056	67·21
April ,,	267	=	8·96	15,565	57·85

The consumption of coke by engines, at the same time, was:—

February, 1881	. . 818 lbs.	=	13·35 lbs. per mile run.
March ,,	. . 785 ,,	=	11·70 ,, ,,
April ,,	. . 649 ,,	=	11·00 ,, ,,

For regular service, there are 8 engines in steam on week-days, of which 6 are on active duty, and 2 in reserve as relief engines. On Sundays and holidays, there are 11 engines in steam. On week-days, the average number of hours on duty with trains, is 10 hours 8 minutes; and in steam, 12 hours 40 minutes. On week-days, one car ordinarily is run as a train, weighing from 2 tons 18 cwt. to 3 tons empty, or, with 46 passengers, an average of 6 tons 7 cwt. gross. Twice a day, two cars are run for workmen's trains; and on Sundays also: making a load of 12½ tons gross, which is as much as the engines can do on the heavier inclines.

Assuming that the general average weight of the train is 7½ tons, and of the engine with fuel and water 6½ tons; the gross average weight moved would be 14 tons for each engine; and the fuel, 11·8 lbs. consumed per mile, would average ·85 lb. per ton-gross per mile.

Merryweather.—Dewsbury, Batley, and Birstal Tramway.

The Dewsbury, Batley, and Birstal Tramway, already described, is made with an easy falling gradient of about 1 in 200, from Birstal to Dewsbury. It is worked with Merryweather engines, condensing, having 6½-inch cylinders, with a 10-inch stroke, and four coupled wheels, 2 feet 2 inches in diameter.

The Batley Engines are illustrated by Figs. 291 to 294. The cylinders are placed inside the framing, and are joined together at the middle, where they form the valve-chest, whilst a saddle is placed on each half, for the purpose of supporting the boiler at the smoke-box. The guide-bars are of steel, the crosshead is of cast steel, and the crosshead-slippers are of cast iron, having large wearing surfaces. The guide-bars are supported by a cross plate, which they considerably overhang in the direction of the

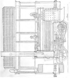

FIG. 252. Tramway Locomotive, by Merryweather & Sons, for the Dewsbury, Batley, and Birstal Tramways.—Longitudinal Section. Scale [illegible].

fire-box. The guides for the valve-spindles are carried by the same plate. The link-motion is of the ordinary shifting-link type. The excentrics and hoops are of cast iron. The coupling-rods are made with solid ends, having phosphor-bronze bushes. All the oil-cups are forged or cast solid on the moving parts.

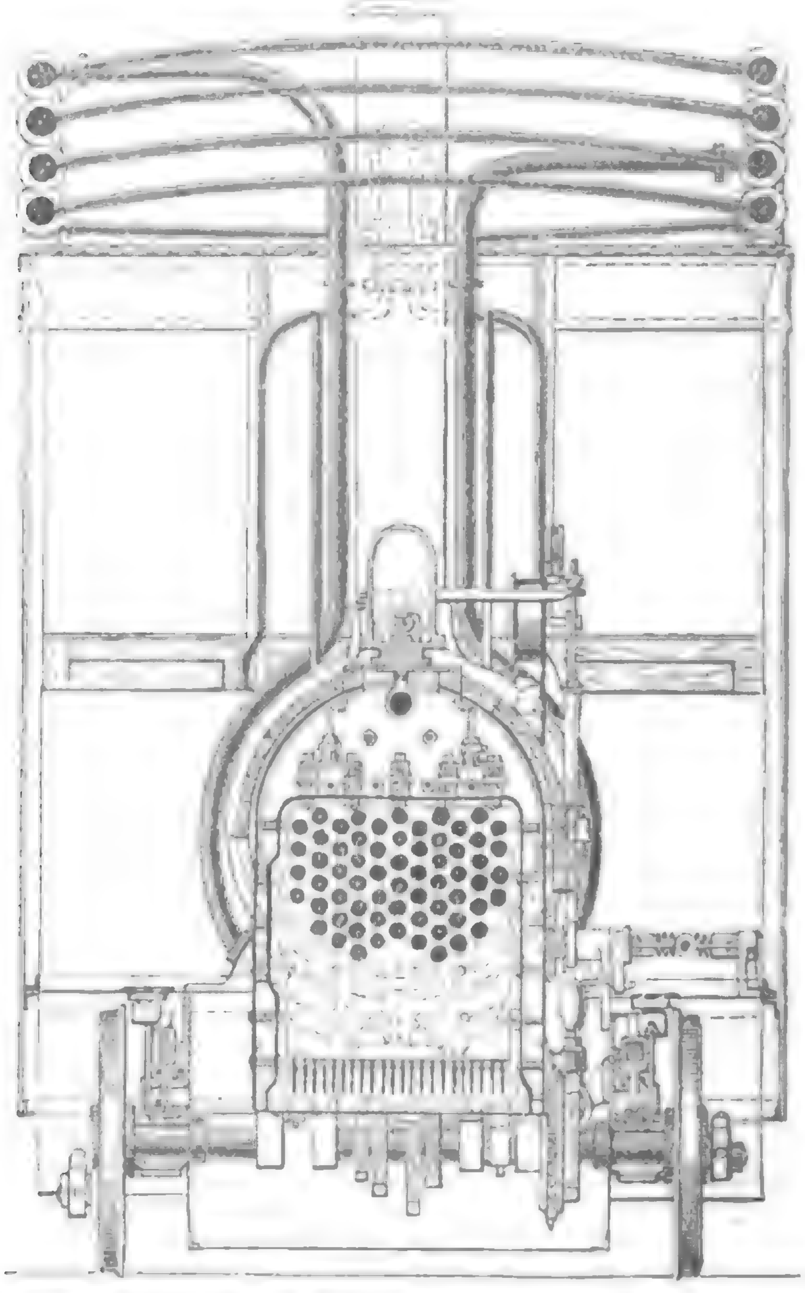

FIG. 292. Merryweather's Engine.—Transverse Section. Scale $\frac{1}{32}$.

The wheels and axles are of steel, the crank-pins in the wheels are casehardened. The brake is applied to all the wheels. The boiler is of the usual locomotive type, of Lowmoor iron throughout, double-riveted in the longitudinal seam. It is fed by a feed-pump driven by a special excentric, and by Giffard's injector.

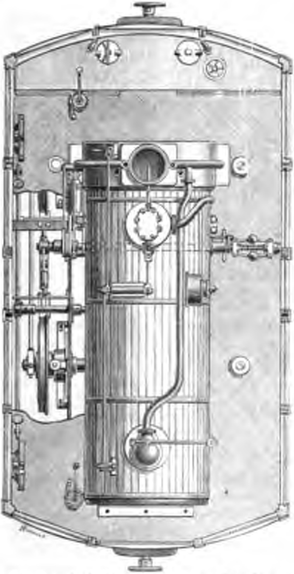

FIG. 293. Merryweather's Engine.—Plan above foot-plate. Scale $\frac{1}{32}$.

The whole of the engine-work has been made of unusual strength, in order to provide for wear and tear by dirt, dust, and rough usage.

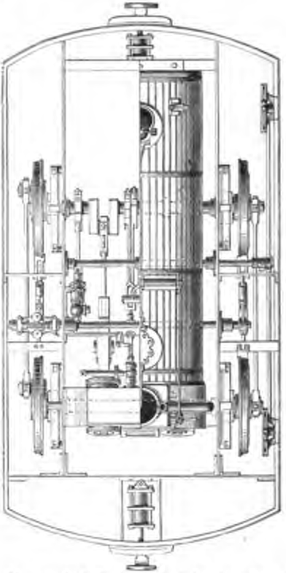

FIG. 294. Merryweather's Engine.—Plan below foot-plate. Scale $\frac{1}{32}$.

The feed-tank, holding 100 gallons, is placed in front of the

Google

smoke-box. A fender-plate is fixed at each end of the engine, to remove obstructions, and to obviate any chance of running over any person. Plates are also run along each side to conceal the wheels and the coupling-rods. The whole of the work is enclosed in a cab or casing of sheet-iron on angle-iron framing, 12 feet in length, 6 feet 4 inches in width, and about 8½ feet above the rails.

The condenser, placed above the roof, consists of four horizontal layers, slightly arched, of thin copper tubes, laid transversely across the roof. The tubes are 1 inch in diameter outside, No. 26 wire-gauge, or $\frac{1}{64}$ inch in thickness, and are each 6 feet in length. There are 60 tubes in each layer, or 240 tubes in the four layers, coated with brown varnish to augment their radiating power. They are brazed at the ends into 3-inch longitudinal pipes, 3 inches in diameter outside, four on each side, 11 feet long. The exhaust-steam is discharged by two copper pipes, one to each side, into the uppermost longitudinal pipe, whence it circulates through the transverse tubes. The condensation-water and the remaining vapour are conducted into a separator-vessel at the front, whence the water runs down to the feed-water tank, and the vapour passes away into the smoke-box, where it is mixed with, and disappears with the products of combustion. So efficient is the condenser that the engine can be worked all day with one charge of the feed-water tank. This tank holds only 100 gallons, and the quantity consumed as uncondensed steam or otherwise does not exceed 50 gallons for the day.

The engine is fitted with apparatus to fulfil the requirements of the Board of Trade. A ball-governor placed over the foot-plate at one side is provided for the purpose of shutting off the steam, and turning on a steam-brake, when the maximum speed allowed—10 miles per hour—is reached. The steam-brake may also be turned on by means of a small pedal placed near the foot of the driver. Steam-levers and reversing-levers are fitted in duplicate, one of each at each end of the engine, so that the driver may take his place at the leading end of the engine, whichever end goes first. A speed-indicator is also erected. The governor is driven by means of a pitch-chain from the crank-shaft, and the speed-indicator is driven by a band from the governor-spindle.

The fire-box is 1 foot 10 inches long by 2 feet wide, inside; and is 2 feet 1½ inches high above the grate. The barrel of the boiler is 2 feet 4 inches in diameter inside. There are 64 flue-tubes 1¼ inches in diameter outside, and 5 feet in length. The grate-area is 3·8 square feet, and the heating-surface is 169·2 square feet, or 44½ times the grate-area. The condensing surface of the condenser amounts to 377 square feet for the 1-inch tubes, and 69 square feet for the longitudinal pipes; together, 446 square feet of condensing surface.

The working pressure of steam in the boiler is 140 lbs. per square inch. There are two safety-valves on the boiler, one of which is a lock-up valve. Steam escaping by the safety-valves is conducted to the exhaust-pipe, and thence into the condenser. The steam is supplied to the cylinder through a perforated steam-pipe at the upper part of the boiler. The cylinders are, as before stated, 6½ inches in diameter, with a stroke of 10 inches. The wheels are 2 feet 2 inches in diameter, placed at 4½ feet centres. The whole of the machinery is encased from below. The weight of the engine, empty, is 6 tons; and, in working order, with water and fuel, 7 tons. The price of the engines was about £750 for each engine, or at the rate of £125 per ton of the net weight.

Engine.	Commenced running.	Miles run, by March 22, 1881.
No. 1	April 10, 1880	15,000
No. 2	Oct. 30 ,,	8,000
No. 3	Dec. 7 ,,	6,000
No. 4	Dec. 11 ,,	5,900
No. 5	Jan. 1, 1881	4,800
	Total miles run . .	39,700

The weight of one car drawn is 2 tons 4 cwt. and of 11 passengers—the average number—16 cwt.: together, 3 tons. Add the weight of the engine itself, 7 tons, making the gross load drawn 10 tons. Occasionally, an extra car is attached, and it is taken with ease. The length of the line is 3¼ miles, and in the course of the journey the train, passing through a continuously populated district, is pulled up from 15 to 25 times each way. The double-journey of 6½ miles is performed in 65 minutes, including all stoppages—making an average speed of 6 miles per hour.

The total weight of coke—Straker & Son's—consumed in running the mileage, 39,700 miles run, was 122½ tons, costing 23s. 6d. per ton; being at the rate of 6·911 lbs. per mile, costing ·872d. per mile; or ·69 lb. per ton-gross per mile.

The wages of drivers is 5s. per day; of cleaners, 2s. 6d.; coke-and-water men, 2s. 6d.; mechanic, 8s. 4d.

The working expenditure per day, running 72 miles, is as follows (March, 1881):—

	s.	d.
Coke	5	2¾
Water, 150 gallons, including water for washing out	0	1½
Oil, 1¼ pints	0	6
Waste, ½ lb.	0	1½
Driver's wages	5	0
Cleaner's wages, proportion	1	0
Coke-and-water man's wages, do.	0	6
Mechanic's wages, do.	1	6
Total expenditure per day	13	11¾

equivalent to 2·33d. per mile run. The cost for repairs, included in the above, has been but nominal, for the time the engine has been at work. The springs have given a little trouble by breakage, caused, it was believed, by deficiency of strength of the way, which was not constructed for engine-haulage.

For comparison with the cost above given, of working the traction by engine-power, Mr. Truswell gave the cost for horse-power, where two horses are harnessed to the car, for which service he employs a stud of eight horses. For provender, water, driver's and stableman's wages, proportion of wages of a man for chopping and mixing provender, shoeing, harness, and veterinary services, the cost is at the rate of 4½d. per mile run by the car—

about double the cost for engine-power. The comparison is necessarily imperfect.

MERRYWEATHER.—STOKE-ON-TRENT AND DISTRICT TRAMWAYS.

Two engines constructed by Messrs. Merryweather & Sons for the servive of the Stoke-on-Trent and District Tramways, on a gauge of 4 feet, are arranged similarly to the Batley engines; but they are larger in dimensions, and are fitted with an ordinary water-condenser, placed in the roof of the engine-house or cab. The engine, Fig. 295, has 7½-inch cylinders, with a stroke of 12 inches, and four coupled wheels 2 feet 4 inches in diameter, at 4½ feet centres. The barrel of the boiler is 2 feet 6 inches in diameter inside; the fire-box is 2 feet 2 inches square, and 2 feet 7 inches high above the grate. There are 78 flue-tubes 1¾ inches in diameter outside, and 5 feet long. The grate-area is 4·8 square feet, and the heating surface is 197·3 square feet, equal to 41 times the grate-area. The condensing tank holds 400 gallons. The total length of the engine is 13 feet, and the width is 6½ feet. The weight, empty, is 7½ tons; with fuel and water, 10½ tons. The exhaust-steam is delivered from the exhaust-pipe, at a level above the top of the tank, into a concentric chamber, whence it escapes through an injector, or inductor, within the tank, placed horizontally on the floor of the tank. A continuous circulation of the water is thereby set up, and all the water is brought successively into contact with the steam to condense it. At the summit of the cylindrical exhaust-chamber there are two small vacuum-valves, through which air is admitted, destroying any degree of vacuum that may be formed in the chamber, and so preventing back-flow into the cylinders. Overflow from the tank is conducted to the feedwater-tanks, in front and below the foot-plate. Steam from the safety-valves is conducted into the smoke-box, whence it passes off with the gaseous products of combustion. The price of the engines was about £800 each.

The Stoke line has severe and continuous gradients, some of them being 1 in 16, others 1 in 18 and 1 in 20. The cars weigh from $2\frac{1}{2}$ to 3 tons, and are constructed to carry 48 passengers;

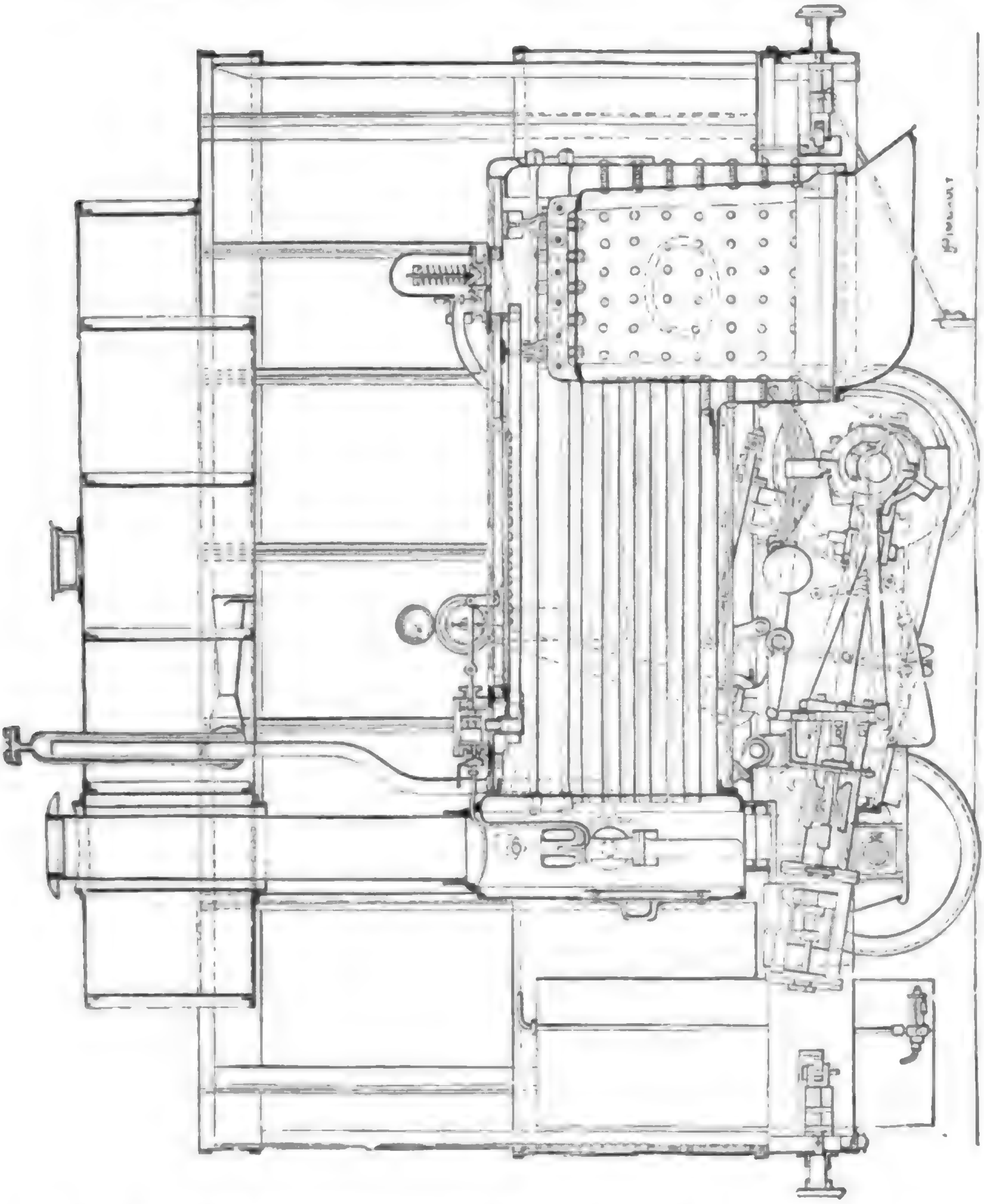

FIG. 295. Tramway Locomotive, by Merryweather & Sons, for the Stoke-on-Trent and District Tramways.—Vertical Section. Scale $\frac{1}{32}$.

occasionally from 80 to 100 passengers are carried in a car. The engines take with ease a loaded car, weighing with passengers 9 or 10 tons, up the steepest inclines, at a speed of from 4 to 5 miles per hour. The two Merryweather engines commenced operations in April, 1881. Additional engines, constructed by the same firm, were employed to work the extension to Hanley and Burslem, having 10-inch cylinders, with a stroke of 15 inches. It may be questioned whether there is to be found in England any worse combination of circumstances than those which have to be met in the working of the Stoke line.

HUGHES.

Mr. Henry Hughes brought out, early in 1876, a tramway locomotive. "The result of my experiments," he said, on his examination as a witness by the committee on Mechanical Power on Tramways, "is that I have produced an engine of the ordinary locomotive type, which can be worked without showing any steam, which is practically noiseless, and in which we can keep up the steam without the aid of a blast; and it shows no smoke because we use coke as a fuel. It is covered in similarly to an ordinary car, and consequently does not frighten horses more than ordinary cars do." These are, concisely stated, the conditions for the success of mechanical power on tramways.

The means for condensing the exhaust-steam, which is the novel feature of this engine, was patented in January, 1876. Each blast of exhaust-steam is, by an automatic action, condensed as it issues from the exhaust-pipe, by a shower of cold water, let off in regulated quantities at the instant of the exhaust. The exhaust-steam, arriving by a branch from the exhaust-pipe, blows open a valve on the end of the branch, and escapes into a small chamber —the condenser. By the same impulse, another valve in the bottom of a water-tank, connected with the exhaust-valve, and moving simultaneously with it, is opened, and discharges water into the condenser. The exhaust-steam is condensed by the water, a partial vacuum is formed in the condenser, and the water-valve is consequently closed by the external pressure. The resulting mixture, consisting of hot water, is discharged at a temperature of 170° F., into a receiving tank. Within this limit of temperature, there is not much visible vapour disengaged from the discharged water. When the temperature is allowed to rise above 180°, a good deal of visible vapour escapes. The supply of feed-water for the boiler is drawn from this tank, and the remainder of the hot water is ejected during the journey, or at the end of the trip.

It is stated that, on a level line, the condensing water is consumed at the rate of from 25 to 30 gallons per mile. The fire is made up at the beginning of the trip, and is not touched during the passage. According to Mr. Hughes, a fire lasts for a ten-mile run without requiring fresh stoking.

The first public trial of Mr. Hughes's tramway locomotive was made on the Leicester Tramways, on March 27, 1876. A run of four miles was made, a portion of which was on an ascending gradient of 1 in 22. The engine had two 6-inch cylinders, having a stroke of 12 inches, connected direct to four coupled wheels, 2 feet in diameter, on a wheel-base of 4 feet. The boiler, of the locomotive type, had 120 square feet of heating surface. The whole of the boiler and the machinery was enclosed in a wooden structure resembling a section of a tramway-car; the wheels and side-rods were concealed by sheet-iron plates. The chimney rose through the roof of the car, and by its length sufficed for the natural draught required to keep up the steam, which was maintained at a pressure of about 120 lbs. per square inch. The furnace was supplied with a sufficient quantity of fuel to last the journey. The quantity of condensing water carried amounted to 300 gallons, which, it is said, would suffice for a trip of six miles on ascending inclines, in cold weather. The weight of the steam-car, in working order, was about 5 tons.

The locomotive was coupled to a one-horse car, constructed to carry 16 inside. During the trial it carried 25 persons, and the total weight of the car, with its load, must have been about 3½ tons, making the gross weight of the train about 8½ tons. The speed was generally about 8 miles per hour, and one or two steep inclines on bridges were steadily surmounted, at a lower speed. During the whole of the trip, there was no visible escape of steam. except on one occasion, in surmounting a steep incline, when a little steam escaped, which quickly disappeared.*

The same engine, according to Mr. Hughes, was used on the Leicester line every day for some weeks, on passenger traffic. The average pace was six miles per hour.

Mr. Hughes's engines have also been at work experimentally on the tramways at Edinburgh and at Sheffield, and on the Vale of Clyde Tramways at Glasgow. The traffic of this line was worked by steam-power, under a contract made with Mr. Hughes, commencing July 21, 1877, at the rate of 5½d. per mile run. The contract expired July 21, 1880, and was renewed for one year, at the rate of 6¾d. per mile run.

HUGHES.—WANTAGE TRAMWAY.

On the Wantage Tramway, one of the Hughes engines has been working for some years. The line, which has already been noticed, is constructed like an ordinary railway, with raised rails on longitudinal sleepers. The engine makes eight trips each way, —40 miles a day. The trip is performed in 32 minutes, or at the average speed of 9·4 miles per hour. Two cars are taken by the engine, weighing, with their load of passengers, an average of 6½ tons. The engine weighs in working order 6¾ tons, and the gross weight of the engine and train amounts to (6¾ + 6½ =) 13¼ tons. The fuel (coke) is consumed at the rate of about 307 lbs. per day, or 7·67 lbs. per mile run, equivalent to ·58 lbs. of coke per ton-gross per mile.

HUGHES.—SOUTHERN TRAMWAYS OF PARIS.

Twelve of the Hughes engines, shown in longitudinal section, Fig. 296, similar to the engines on the Vale of Clyde Tramway,

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* The particulars of this trip are derived from *The Engineer*, March 31, 1876, page 232.

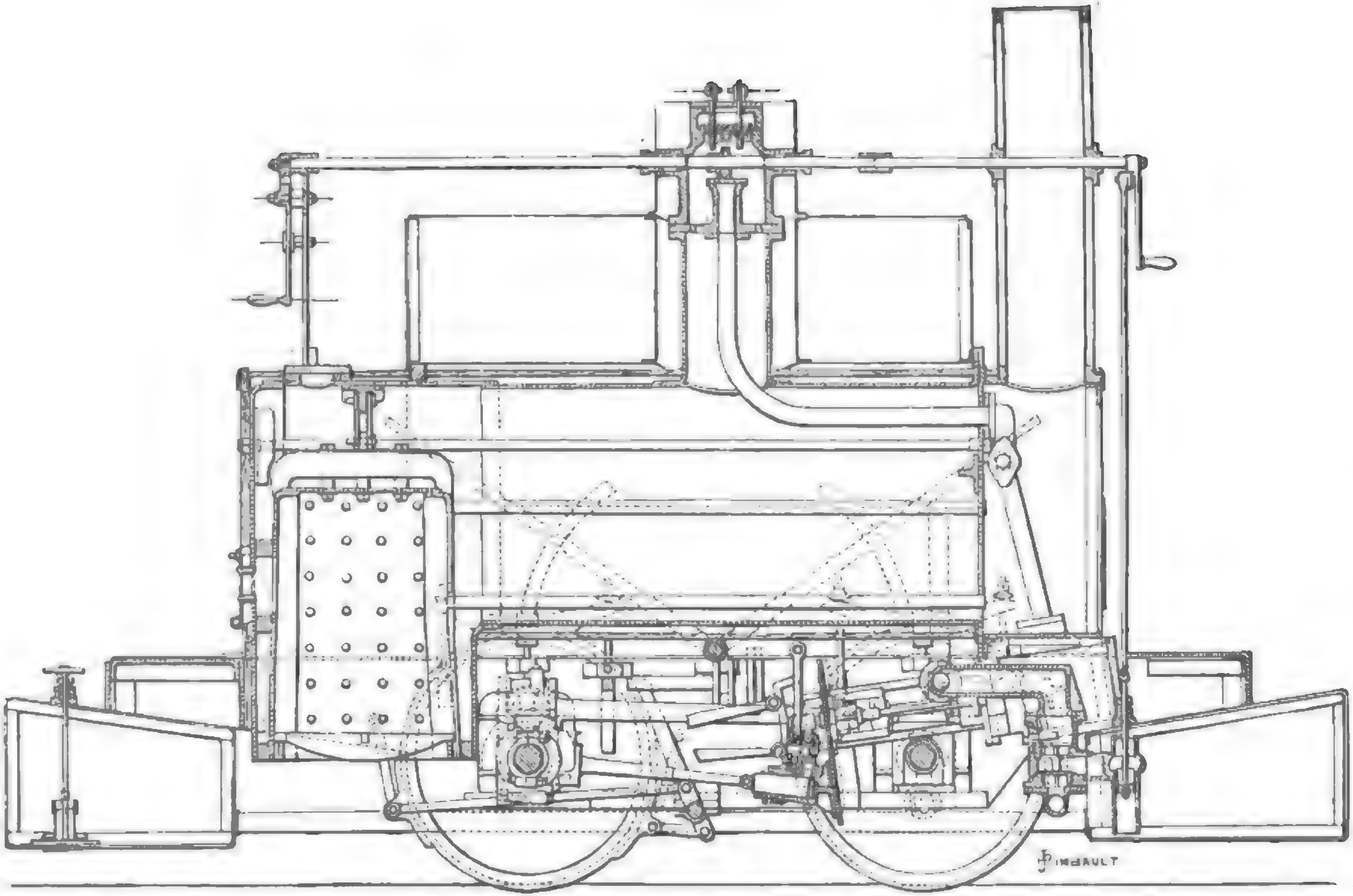

FIG. 296. Tramway Locomotive, by Hughes's Locomotive Company, for the Southern Tramways of Paris.—Longitudinal Section. Scale $\frac{1}{15}$.

were constructed for the Bastille-Charenton line of the Southern Tramways of Paris. They are on four wheels, coupled, 2½ feet in diameter. The cylinders are 7 inches in diameter, with a stroke of 12 inches. The boiler is of Lowmoor iron, 2 feet 3¾ inches in diameter inside. The fire-box is of copper, 1 foot 10¾ inches long, 2 feet 1 inch wide at the grate, and 2 feet 5 inches high to the roof, above the grate. The plates are ⅜ inch thick, except at the tubes, where the plate is ⅝ inch thick. There are 62 brass tubes, 1½ inches in diameter outside, and 5 feet 7⅜ inches long, with a clearance of ⅞ inch between the tubes. The grate-area is 3·70 square feet; the total heating surface is 149½ square feet. The working pressure in the boiler was from 80 lbs. to 100 lbs. per square inch. The exhaust-steam is condensed in a lower water-tank by water from the upper tank, in the manner already explained, and indicated in the Fig. 296, and in detail, Fig. 297. The piston-valve in the front lower tank is opened by a rod connected with the regulator-handle, making a communication between the tank and the condensing chamber between two valves, which constitute a double-beat valve. The exhaust-steam from the pipe below forces open the valves, and escapes into the condensing chamber, and is met and condensed by cold water from the pipe leading from the upper tank. The water is thus heated to a temperature of about 170° F., and is collected in the lower tanks, whence the boiler is fed by means of a pump or an injector.

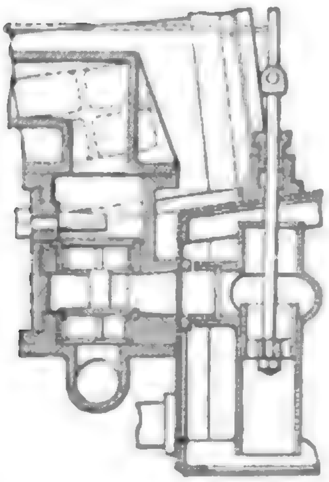

FIG. 297. Hughes' Tramway Locomotive. —Feedwater heater.

The Bastille-Charenton line is 4·1 miles in length. The steepest gradients on the line are, one of 1 in 29 for 100 yards, and one of 1 in 20 for the same length. The engines weighed 5½ tons empty, and 7½ tons in working order. The regular duty was to draw one car, weighing 2·55 tons, constructed to carry 46 passengers. Assuming that the car was half filled with passengers, weighing 1·6 tons, the gross weight moved amounted to 11·65 tons. The journey of 4·1 miles was run in 35 minutes, being at the rate of 7 miles per hour. Four engines were at work daily, making each about 67 miles per day. The fuel (coke) was consumed at the rate of 17 lbs. per mile run; equivalent to 1·46 lbs. per ton gross per mile. The expenses averaged as follows:—

		Per mile. d.
Coke, 17 lbs.	per mile, @ 24s. 2d. per ton	2·218
Oil, ·42 lb.	,,	1·840
Tallow, ·034 lb.	,,	·148
Water, 40 galls.	,, for feed and condensing, 4d. per 1,000 gallons	·160
		4·366
Wages of drivers, labourers, cokemen, &c.		2·357
Running expenses		6·723
Repairs		2·702
Total working cost		9·425

The contract payment for the engine-service was at the rate of 45 centimes per kilometre, equivalent to 6·9d. per mile run, for drawing 1 car. For 2 cars, the payment was 60 centimes, or 9·2d. per mile run. The contract, which commenced in August, 1879, was brought to an end in February, 1880; when the work of traction was resumed by means of horse power.* Although the steam-haulage was conducted at a loss, the immediate cause of the termination of the contract was the breaking down of the engines by lodgment of a compound of grease and lime on the walls of the fire-boxes,—the grease derived from the condensed steam and the lime from the water—by which the fire-boxes became overheated and bulged inwards, and the flue-tubes leaked and broke.

In explanation of the large consumption of fuel, it must be stated that the way was in wretched order. It was too weak, having a mean sort of rail of hollow section, without strength. The wave-movement of the rails, in advance of the engine, was beyond description. The tractional resistance may easily be conceived to have been double what it would have been with a good way.

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* For the particulars of performance of the Hughes engine the Author is indebted to Mr. H. Conradi.

The condensing apparatus employed in the engines, it may be added, was uncertain in action—very fickle; and it caused, it is believed, a considerable degree of back-pressure on the pistons.

HUGHES.—BRISTOL TRAMWAYS.

On the Bristol Tramways, seven of the Hughes engines that worked in Paris were set to work on the Horfield section, which is 1·43 miles in length. It is a severe line to work, being up-hill for four-fifths of the length in one direction—towards Horfield; and downhill for the remaining fifth. The prevailing gradients are from 1 in 24 to 1 in 68. The line runs through a very populous district. The work was done under a contract for 12 months made with the Hughes Engine Company, by means of four engines in steam daily. During the week 1,717 miles were run, of which 261⅝ miles were run each week-day, averaging 65½ miles per engine; and 147½ miles on Sunday.

In these engines, the steam was not condensed. The weight was taken at 7 tons each in working order. One car only was allowed to be hauled by an engine; the car weighing, with passengers, 4 tons. The gross weight of engine and car was thus 11 tons. The fuel (coke) consumed was 12½ tons per week, or at the rate of 16·31 lbs. per mile run, or 1·48 lbs. per ton-gross per mile. Here again the Hughes engines work at a disadvantage, since, besides working up steep gradients in one direction, they were braked for most of the way back, and, to the extent of brakeage necessary, lost the advantage of the aid of gravitation. The contract price paid by the Tramway Company for steam-haulage was 7d. per car-mile run.

HUGHES.—LILLE TRAMWAYS.

Mr. Hughes designed a more powerful class of locomotives for working on the Lille Tramways. In general arrangement, they resembled the engines employed at Paris, already described. The cylinders were 9 inches in diameter, with a stroke of 13 inches; the four coupled wheels were 3½ feet in diameter. The barrel of the boiler was 2 feet 4½ inches in diameter. There were 62 brass flue-tubes 1½ inches in diameter, 5 feet 8⅛ inches long. The fire-box, of copper, was 2 feet 1¼ inches in length, and 1 foot 11¼ inches wide, at the bottom; and was 2 feet 7 inches high above the grate. The area of grate was 3·82 square feet; and the heating surface was 162½ square feet. The exhaust-steam was passed through a feedwater-heater, consisting of a number of brass tubes in a cast-iron box, and thence into the saddle water-tank, in which it was delivered over the surface of the water, or through branching pipes which descended into the water. The steam was discharged under water, in town; and above water, in the country. The tank held 400 gallons of water, which was heated by the exhaust-steam up to the boiling-point, in the course of the trip. For three-fourths of the trip, the condensation was efficiently effected; but for the remaining fourth, it was ineffective. The water was changed for each trip. The pressure in the boiler was from 80 lbs. to 100 lbs. per square inch. The engine weighed, empty, 7½ tons; and, in working order, with fuel and water, 10 tons.

The Lille-Haubourdin line is a level line, 5·138 miles in length. The Lille-Roubaix line is a line of many inclines, of which the steepest is 1 in 22. It is 6·78 miles in length. The lines are both single lines, with passing places. The way is constructed with double rails bolted to chairs, screwed down to cross sleepers. Steam-service was commenced on the Haubourdin line April 6, 1880; and on the Roubaix line July 1, 1880. Payments were made to the contractors (Hughes' Engine Company) at the same rates as were paid to them in Paris; namely, 6·9d. per mile-run with one car; and 9·2d. per mile-run with 2 cars. This contract lasted only four months; after which the engines were hired for one year commencing November 1, 1880.

The averaged results of the performance of engines, on the Haubourdin line, equivalent to the work of one engine for 103 days, running 3,817 miles, or at the rate of 37 miles per day, were as follows. The usual load on week-days was one car, with an extra car between Lille and the depôt, a distance of about 2 miles; on Sundays and holidays 2 cars were taken. It may be assumed that the train averaged 1½ loaded cars:—

		d.
Coke	17¾ ibs. per mile-run, cost	2·250
Oil	·329 lb. ,, ,,	1·410
Tallow	·0362 lb. ,, ,,	·156
Feed water	12¾ gallons ,, ,,	·051
Condensing water	72 ,, ,, ,,	·248
		4·115
1 driver @ 6 francs per day 1 stoker ,, 4 ,, ,,		2·570
Running expenses		6·685
Repairs:—Ordinary		2·455
Extraordinary, tor accidents		·437
Total		2·892
Working charges: running and repair expenses		9·577

From this statement it appears that, in round numbers, the running charges amounted to 6½d. per mile-run, and the cost for repair to 3d. per mile-run; together 9½d. per mile-run. The engines were worked at a disadvantage. They took their turns between horse-cars, and were thus limited to low speeds, with many stoppages, making the trip of 5·13 miles in 55 minutes,—at an average speed of 5·60 miles per hour. They were also compelled to remain from 20 to 25 minutes at one terminus, and from 8 to 10 minutes at the other.

The evaporation of water was at the rate of 7·18 lbs. per lb. of coke, from a temperature averaging probably 140° F.

Assume the average load of 1½ cars, before stated, weighing 2·4 tons per car, with, say, 45 passengers, weighing 3 tons, making together 6·6 tons; and with the engine, 10 tons, a gross weight of, say, 16½ tons, the consumption of fuel was, for this gross weight, at the rate of 1·07 lbs. per ton-gross per mile-run.

Mr. H. Conradi tested the consumption of feed-water by the engines on the Haubourdin line, for the double trip, to and fro, on four occasions. First with 1 car, twice with 2 cars, and once with 3 cars.

1880.	Cars, weight with passengers.	Engine and cars.	Length of run.	Time, including stoppages.	Average speed per hour.	Feed-water consumed per mile-run.	Coke consumed per mile-run.	Water per lb. of coke.	Water per ton-gross per mile-run.	Coke per ton-gross per mile-run.
	car tons	tons	miles	mins.	miles	gall.	lbs.	lbs.	lbs.	lbs.
1. May 5, Windy and Dusty	1 5·3	15·3	10·4	90	6·9	11·15	15·87	7·8	7·43	[illegible]
2. May 16 do. do.	2 9·5	19·5	9·11	60	[illegible]	[illegible]	17·10	8·3	7·30	[illegible]
3. May 23 do. do.	2 9·3	19·3	7·18	60	[illegible]	[illegible]	17·68	8·35	[illegible]	[illegible]
4. June 16 . . .	(with pig iron and rails) 3 15·2	25·2	[illegible]	36	[illegible]	[illegible]	—	—	4·13	—

In the 1st, 2nd, and 3rd double-trips, there were the usual frequent stoppages for passengers. The 4th trial was made specifically to test the capacity of the engine to draw at least 2 cars up the steepest incline on the line, at Croix, a gradient of 1 in 20. It shows that the engine was capable of taking up this incline 1½ times its own weight; and the relatively low consumption of water per mile-run shows most remarkably how wasteful of engine-power are the frequent stoppages incidental to the regular traffic as exemplified in the 1st, 2nd and 3rd trials. The consumption of fuel, which was not actually noted for the 4th trial, did not probably exceed ½ lb. of coke per ton-gross per mile-run.

On the Lille-Roubaix line, the quantities and cost for working the engine-power were as follows:—

		d.
Coke	20·625 lbs. per mile-run, cost	2·700
Oil	·292 lb. ,, ,,	1·000
Tallow	·028 lb. ,, ,,	·120
Water, feed	17·74 galls. ,, ,,	·070
Water, condensing	88·10 ,, ,, ,,	·350
		4·240
Drivers, stokers, cokemen, pointsmen, &c.		2·800
Running charges		7·040
Repairs:—Ordinary		2·175
Extraordinary (Accidents)		·250
		2·425
Working charges:—Running and repair		9·465

The line was generally in very bad order. On soft ground, the sleepers were not properly squared for the chairs. The wheels of the engines jammed between the rails and counter-rails. Waves were raised in the way in advance of the engines. The distance, 6·78 miles, was traversed in 42 minutes, comprising frequent stoppages for passengers in Lille and Roubaix, and at seven intermediate stations. The average speed was 10·17 miles per hour; and the maximum speed frequently rose to from 17 to 18 miles per hour. The time allowed was 60 minutes for the trip, making a speed of 6¾ miles per hour.

Since the engines were hired to the tramway company, the exhaust-steam was not condensed, but was discharged direct into the chimney. The traction company from whom the engines were hired paid for them from £650 to £700 each.

The locomotives, six in number, weighed, empty, 4¾ tons; with fuel and water, 6 tons. They worked up to a pressure in the boiler of 150 lbs. per square inch; but the average pressure was from 100 lbs. to 120 lbs.

FALCON ENGINE AND CAR WORKS.

This company manufacture tramway steam locomotives of three sizes, having respectively 7-inch, 8-inch, and 9-inch cylinders, with four-coupled wheels for the 8-inch engine. The leading data are as follows:—

Diameter of cylinders		7 ins.	8 ins.	9 ins.
Stroke of ditto		14 „	14 „	14 „
Diameter of wheels		30½ „	30½ „	30½ „
Length of wheel-base		4½ ft.	4½ ft.	5 ft.
Working pressure in the boiler per square inch		175 lbs.	175 lbs.	175 lbs.
Heating surface		128·5 sq. ft.	154 sq. ft.	173¼ sq. ft.
Area of firegrate		4·0 „	5·9 „	6·75 „
Ratio of grate to surface				
Extreme length		32·1 ft.	26·1 ft.	25·7 ft.
Extreme breadth		6½ „	6½ „	6½ „
Extreme height above level of rails, with condenser		10 ft. 8 ins.	10 ft. 8 ins.	10 ft. 8 ins.
Ditto, without condenser		9 „ 4 „	9 „ „	9 „ 4 „
Weight, with condenser	empty	7¼ tons.	8 tons.	8½ tons.
	loaded	8½ „	9½ „	10 „
Weight, without condenser	empty	6¾ „	7½ „	8 „
	loaded	8 „	9 „	9½ „
Tractive force		2,249 lbs.	2,938 lbs.	3,718 lbs.
Effective load, exclusive of engine, drawn at a speed of 10 miles per hour, up an incline of	Level.	67 tons.	89 tons.	114 tons.
	1 in 50	22 „	30 „	40 „
	1 in 30	13 „	19 „	25 „
	1 in 20	8 „	4½ „	16 „

The 8-inch engine was one of a number of engines of the same class, constructed for the Burnley tramways at the Falcon Works, from the designs of Mr. Norman Scott Russell, the general manager of the works. It has a locomotive boiler; the cylinders are inside the frame-plates, with a cranked axle. The tractive force, 2,938 lbs., is at the rate of 29·9 lbs. per pound of effective pressure per square inch in the cylinders. The working gear is shut in from below by iron sheeting with suitable doors, excepting only the coupling rods. The horn-blocks have special wood shields.

The air-condenser is composed of 250 very thin copper tubes fixed in thin brass chambers. Any steam remaining uncondensed, as may happen in warm or in damp weather, passes to a water-tank at the front end of the engine. Under ordinary conditions the residuary steam is passed through a change-valve into the smoke-box, where it is superheated, and becomes invisible on passing from the chimney.

Special consideration has been bestowed upon the break power. The speed-regulating governor is driven by an independent wheel, running on the rails and kept down by springs. The wheel of the governor is on the same shaft. The governor works the speed indicator by means of levers, and when the speed of the engine reaches 10 miles per hour a small valve is lifted, and admits steam from the boiler to the car-break and engine-break, and to a small cylinder on the top of the boiler, by which the regulator is closed. This apparatus automatically limits the speed on descending inclines to 10 miles per hour. There is, in addition, a hand break-valve, by which steam may be admitted at any constant pressure to both break-cylinders, and there is a foot-break, by means of which all the wheels can be locked. The steepest gradients are 1 in 17 and 1 in 20. The engines usually take one 46-passenger car. They have taken experimentally two cars with 73 passengers, easily. The consumption of fuel, coke, is stated to be at the rate of from 8½ lbs. to 9 lbs. per mile-run.

KITSON & CO.

The cylinders in this engine, Fig. 298, are placed outside the longitudinal frame-plates, and as high as possible above mud and dust, protected by suitable casings. The engine is on four wheels, coupled. Kitson's patent valve-gear is, with the same object, employed. It is a modification of Walschaert's valve-gear. The ends of a floating lever are linked to the crosshead, the valve spindle, and intermediately at a point near the valve-spindle;

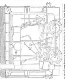


FIG. 298.—Tramway Locomotive, by Messrs. Kitson & Co., for the Birmingham Central Tramways.

the lever is pinned to the radius-link, which receives its rocking movement through an arm linked to the coupling rod. The motion of the valve and its spindle is a compound of two movements: one a movement directly the inverse of that of the piston, on a reduced scale, for the lead; the other a reduced duplicate of the vertical movement of the coupling rod, to open the port for steam. The boiler is of the locomotive type. The exhaust steam is condensed to the extent of two-thirds in a tube-condenser overhead, and one-third is discharged into the chimney, or is condensed by means of a water tank. The engine is provided with a speed indicator and an automatic break. The engines, as employed on the Central Tramways line, Birmingham, weigh, with water and fuel, from 9 tons to 10 tons. They can draw a large car holding 60 passengers.

Messrs. Kitson & Co. construct four standard classes of four-coupled tramway locomotives, as follows:—

	No. of Engine.			
	No. 1.	No. 2.	No. 3.	No. 4.
Cylinders, diameter and stroke . .	7¼ × 12 ins.	8½ × 12 ins.	9 × 15 ins.	11½ × 15 ins.
Wheels, diameter .	2 ft. 4¼ ins.	2 ft. 4¼ ins.	2 ft. 10 ins.	2 ft. 9 ins.
Water-tank, capacity for water .	80 galls.	80 galls.	150 galls.	250 galls.
Weight of engine, empty . . .	6¾ tons	7¼ tons	8 tons	13¼ tons
Weight with water and fuel . .	7½ "	8½ "	10½ "	15¼ "
Net load, exclusive of engine weight, that can be taken up an incline of 1 in 25, at a speed of 6 miles per hour	13 "	16 "	19 "	44 "

The cost for working, repairs, and maintenance of Messrs. Kitson & Co.'s engines on two lines of tramways, is summarised in the following statements:—

BIRMINGHAM AND ASTON TRAMWAYS:--RULING GRADIENT, 1 IN 17.

	Miles run.	Per mile run by engines.							
		Wages.	Fuel.	Water.	Stores.	Repairs.	Sum.	Depreciation, 10 per cent.	Total.
		d.	d.	d.	d.	d.	d.	d.	d.
6 months ending June 30, 1883 .	61,170	1·44	1·50	·13	·35	·24	3·66	1·27	4·93
12 months ending June 30, 1884 .	176,528	1·41	·90	·09	·08	·80	3·28	1·49	4·77
11 months ending May 31, 1885 .	193,204	1·43	·76	·06	·25	1·12	3·62	1·12	4·74
29 months ending May 31, 1885 .	430,902	1·43	·92	·09	·19	·86	3·49	1·29	4·78

DUDLEY AND STOURBRIDGE STEAM TRAMWAYS:—RULING GRADIENT, 1 IN 15.

	Miles run.	Per mile run by engines.							
		Wages.	Fuel.	Water.	Stores.	Repairs.	Sum.	Depreciation, 10 per cent.	Total.
		d.	d.	d.	d.	d.	d.	d.	d.
6 months ending Nov. 30, 1884 .	57,776	2·06	1·95	·21	·17	·39	4·78	1·39	6·17
6 months ending May 31, 1885 .	62,128	2·14	1·95	·21	·39	·70	5·39	1·22	6·61
12 months ending May 31, 1885 .	119,904	2·10	1·95	·21	·29	·55	5·10	1·30	6·40

WILKINSON.

The worm-geared condensing tramway locomotive of Mr. W. Wilkinson combines a few original elements. Acting on the results of Mr. Dewrance's experiments on the evaporative activity of different parts of a locomotive boiler, Mr. Wilkinson designed a short locomotive boiler, having flue tubes only 12 inches in length. His object was to maintain the water level in the boiler practically constant whether on level ground or on steep incline such as 1 in 11. The tubes are not straight, but of an ogee form, in order to yield to expansion without the liability to breakage. The steam is exhausted into a condenser fitted with tubes also of ogee form presenting between 200 and 300 square feet of condensing surface. The steam surrounds the tubes, and the air for cooling them is drawn through them into the ash pan to support combustion. The steam that remains uncondensed passes into a superheater in the smoke-box—a rectangular box fixed against the tube plate, traversed by tubes coincident with those of the boiler, through which the burnt gases flow into the smoke-box.

While running on a level line, with a heavy load, in or nearly in mid-gear, there is scarcely sufficient steam left uncondensed to cause the necessary draught, and in such a case the draught is sharpened by reducing the blast orifice, in applying a thimble to the top of the blast pipe, which is done by hand with a lever.

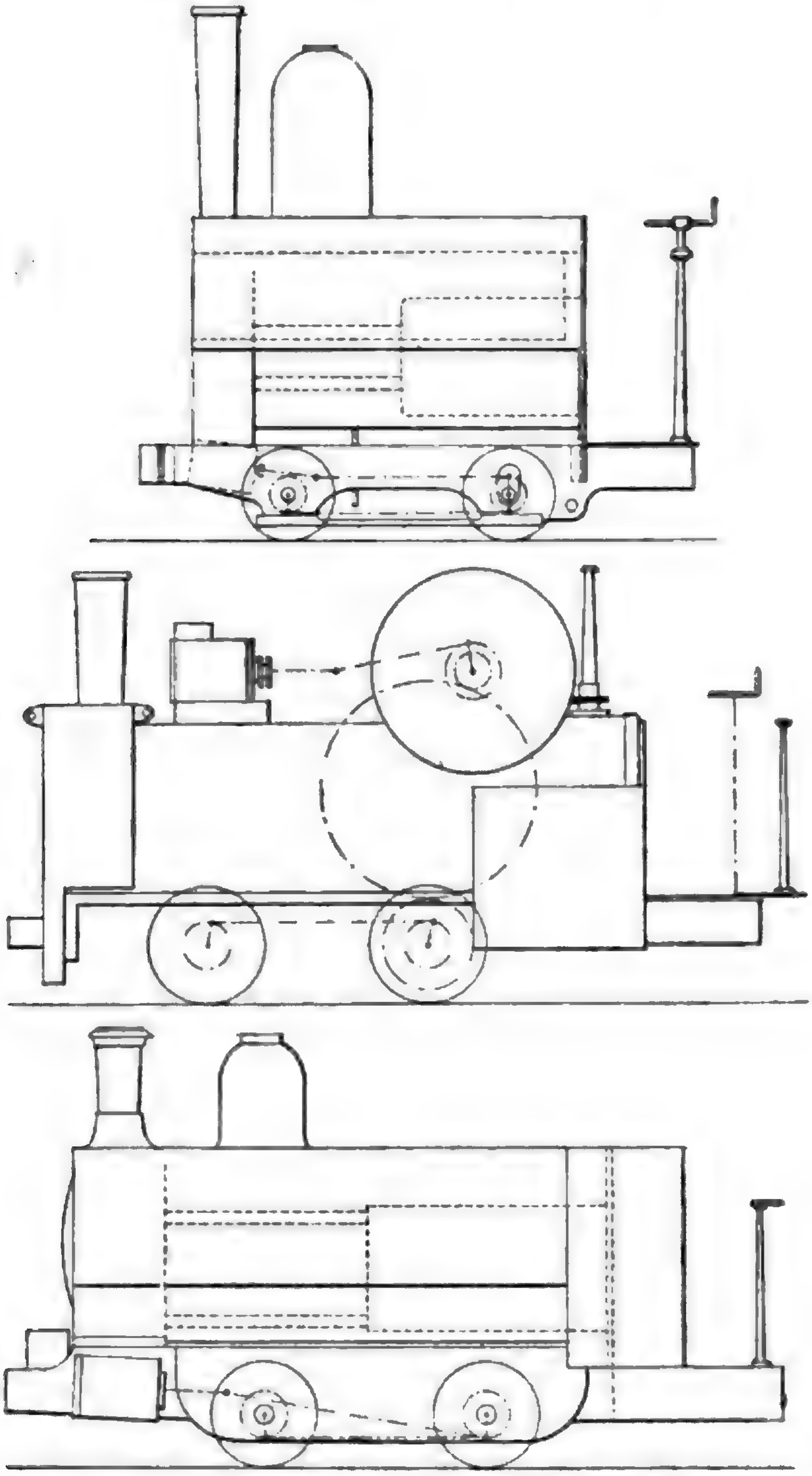
In the fire-box a number of Field tubes are fixed to the roof between the roof-stays.

The power of the engine is transmitted through worm-gear to the driving axle. The worm is double-threaded, and one turn of the axle is made for 7½ turns of the worm. The diameters of the worm and the wheel are equal, or nearly so—about 12 inches in diameter; and the obliquity of the worm-thread is so considerable that, on a falling gradient of 1 in 70, the worm is propelled by the force of gravity. The worm is of Siemens steel, and the toothed wheel runs in an oil bath, providing constant lubrication. The carrying wheels are 3 feet 2 inches in diameter. There are two cylinders working to a longitudinal crank-axle. It is stated that the engine can draw a loaded car, weighing 3 tons, full of passengers, on a level or nearly level road, with the valves in mid gear; the steam being cut off at 9 per cent. of the stroke. At the regulation speed of 8 miles per hour, the speed of the pistons is 436 feet per minute. The engine has been worked at a speed of 16 miles per hour. The machinery is compactly placed, and the cylinders, guide bars, valve gear, foundation plate, worm, and plummer-blocks can be removed for repair by undoing six bolts, and a duplicate substituted.

GEOGHEGAN.

The tramway system of Guinness's Brewery has already been noticed, page 290. The rolling stock comprised, in 1888, nine locomotives and 177 waggons. The first engine, Fig. 299, weighing about two tons, is suitable only for light work, and the gearing being so close to the ground, is difficult to keep in order when working full time. Geared engines, Fig. 300, were obtained, weighing about 5 tons. They were found very useful, but for want of bearing springs, they were slow in speed, costly in repairs, and hard on the road. They were also troublesome in starting. The next class of engine, Fig. 301, weighing 6 tons, having outside cylinders, circular ends for footplates, and water tanks for condensing the exhaust-steam, proved better adapted to the traffic. The motion being all outside, was readily accessible; but, being so near the ground, it got very dirty, and the wear necessitated very frequent adjustment. Case-hardened eccentrics and straps made an improvement.

To combine the best points of these three classes of engines, and obviate their defects, Mr. Geoghegan designed the locomotive shown in Fig. 302. Facilities are given for getting out the wheels and axles, and the cylinders and motion are placed on the top, out of the dirt, and very accessible for cleaning and repair. The spring frame is independent, and is formed of eight steel leaves in four pairs, two pairs at each side, one pair on the top of each pair of axle-boxes, and the other pair under the bottom. It is attached to back and front stays, so that by removing the pins and coupling-rods, and lifting the engine, the spring-frame with wheels and axles and break gear, can be run out for examination and



FIGS. 299, 300, 301. Guinness's Brewery: Tramway Locomotives.

repair. The upper or crankshaft axle-boxes work between horn-plates, and they are each connected with the spring-frame by a vertical link, of which the upper pin is lengthwise of the engine, and the lower pin is crosswise, giving freedom for oscillation.

The break-gear consists of a steam cylinder having two pistons, between which steam is admitted for applying the breaks.

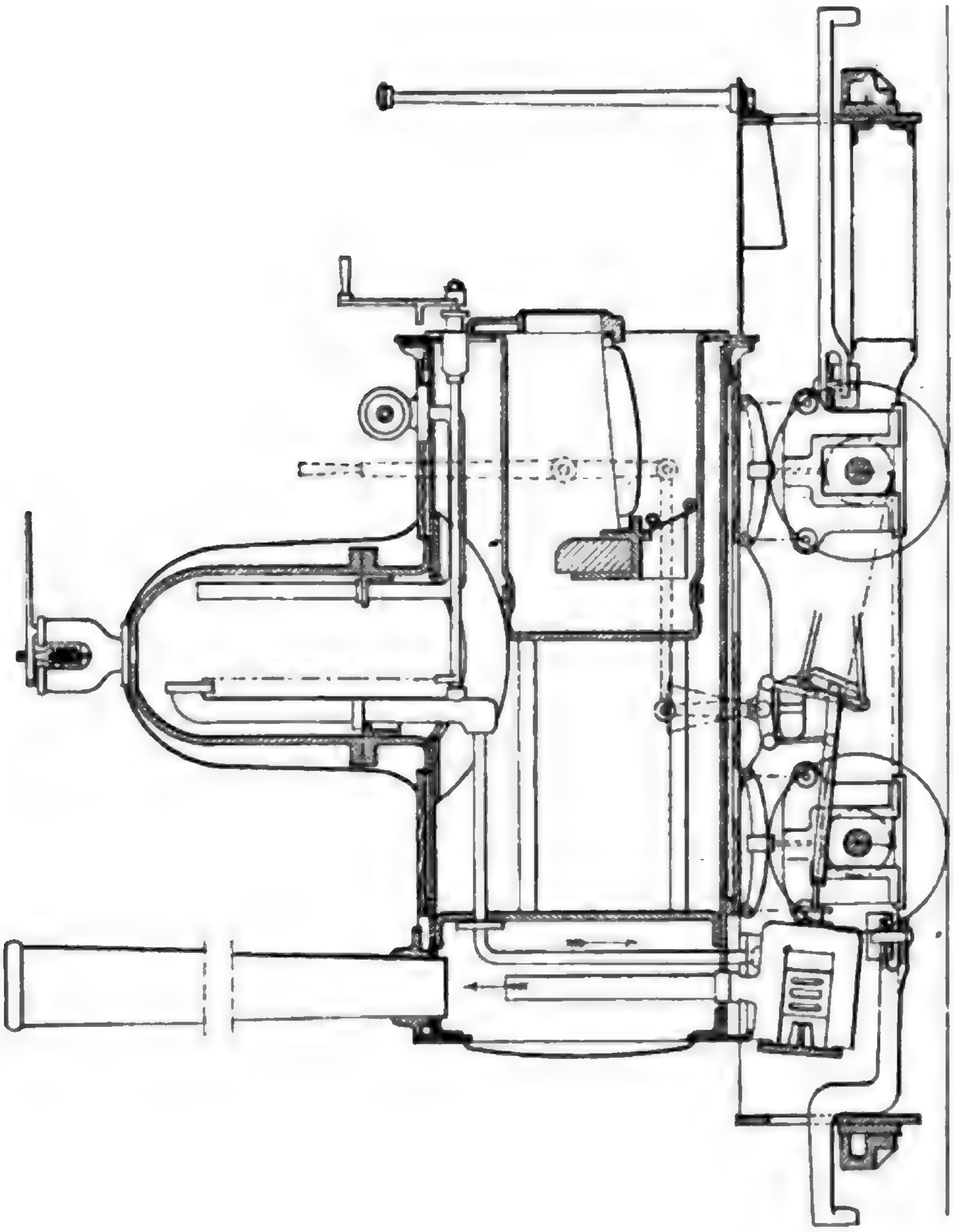


FIG. 302. Guinness's Brewery: Tramway Locomotive, latest design, No. 4.

The boiler is of the Ramsbottom type. The barrel is 2 feet 5 inches in diameter, having 64 tubes 2 feet 10⅜ inches long, 1½ inches in diameter outside. The heating surface is 72·61 square feet in the tubes, 13·75 feet in the fire-box; together 86·36 square feet, or 27 times the grate-area, which is 3·24 square feet. The working pressure is 180 lbs. per square inch.

The cylinders are 7 inches in diameter, with a stroke of 8½ inches. There are four coupled 22-inch wheels, on a wheel-base of 3 feet. The weight on the leading wheels is 3·6 tons, on the trailing wheels 3·8 tons; total weight, 7·4 tons. The gauge is 22 inches.*

ASPINALL.

Shunting engines of 18-inch gauge are employed by Mr. John A. F. Aspinall at the Horwich Locomotive Works of the Lancashire and Yorkshire Railway, for the movement of moderately heavy weights from workshop to workshop, over a large area of ground, laid out with tramways of 18-inch gauge. These tramways, which have already been described (page 292), comprise several miles of way. The works are on practically level ground, and in virtue of the narrowness of the gauge, there are facilities for passing in and out of the narrow doorways of the workshops, on quick curves which are not greater than 13 feet in radius.

The locomotives employed (Fig. 303), were designed and constructed by Mr. Aspinall. They are four-wheel coupled, similar to those of Mr. Geoghegan (page 475). The cylinders are 5 inches in diameter, with 6 inches of stroke; the wheels are 16¼ inches in diameter, on a wheel-base of 2¾ feet. The frame is 7 feet 4¼ inches long; the extreme width of the engine is 3 feet. The boiler is of steel, cylindrical, 2¼ feet in diameter, 5 feet 2 inches long; containing an iron cylindrical fire-box, 17 inches in diameter, 2¼ feet long, and 55 tubes in sequence, 1⅜ inches in outside diameter. The fire-grate is about 1 foot long, and has an area of 1·78 square feet. The heating surface of the fire-box is 10·42 square feet; of the tubes, 36·12 feet; together 46·54 square feet, or 26·1 times the grate-area. The capacity of the tank is 26½ gallons. The working pressure is

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* See a paper by Mr. Samuel Geoghegan, "Description of Tramways and Rolling Stock at Guinness's Brewery," in the *Proceedings of the Institution of Mechanical Engineers*, July, 1888, page 327.

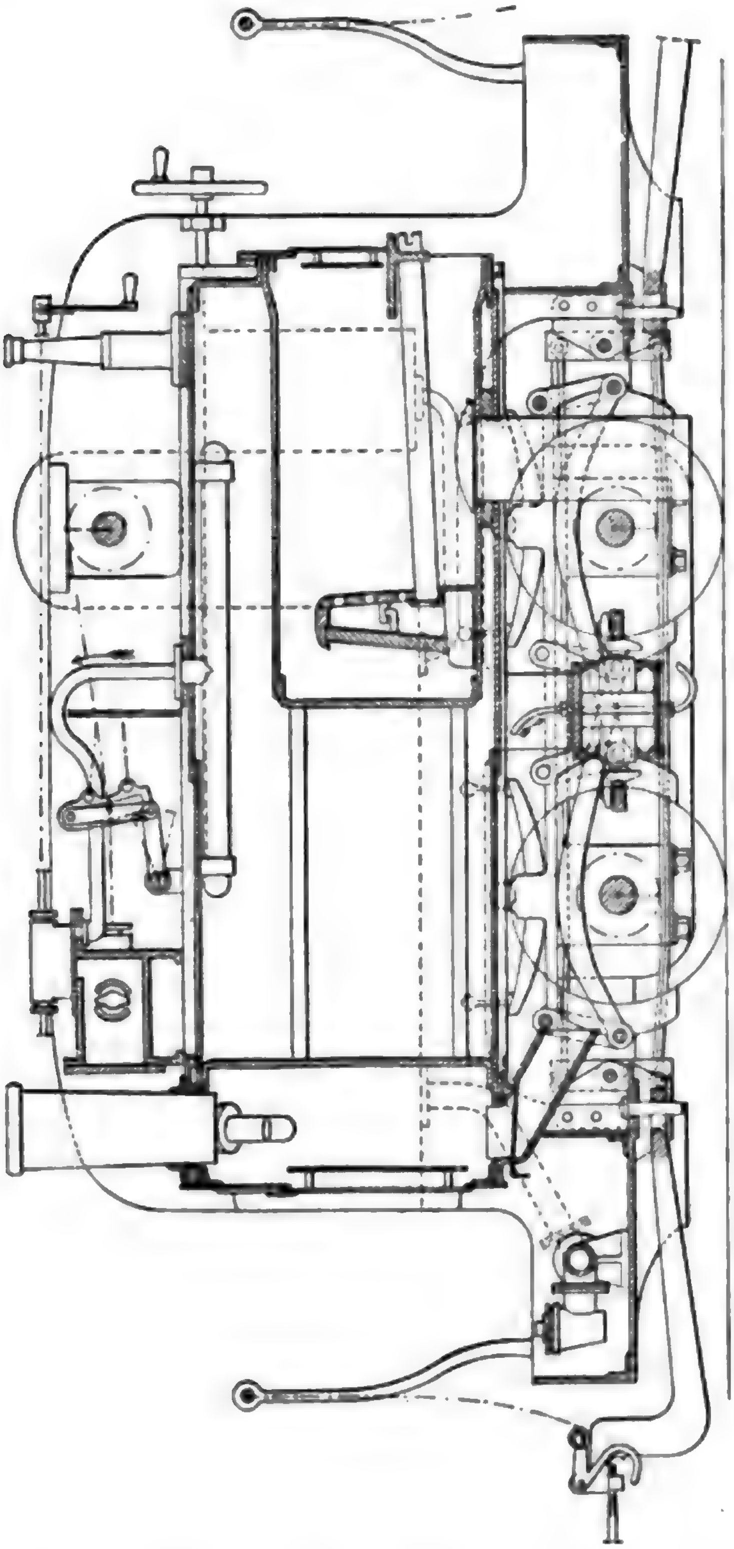

FIG. 303. Horwich Locomotive Works: Tramway Shunting Engine.

170 lbs. per square inch. The weight, empty, is 2·80 tons; full, and in working order, 3·19 tons. The tractive force is computed

as 1,412 lbs., or 9·22 lbs. per pound of effective pressure per square inch on the piston. The height of the horizontal centre-line of the boiler is 2 feet 9½ inches. The top of the chimney is 7 feet 4½ inches high above the level of the rails.

PERRETT.

Mr. Edward Perrett arranged a steam car, Figs. 304, 305, in which the machinery is placed horizontally under the frame, and two vertical steam-boilers are placed on the platform, one at each end of the car, and connected together. The weight is thus equally distributed, and the car may be run either end foremost. The car runs on eight wheels, and weighs 8 tons when loaded, of which 5 tons rest on the four middle wheels, which are driven by the engine, and 3 tons is divided between the fore pair and aft pair of wheels. These wheels, fore and aft, are arranged as Bissell trucks, radiating outwards on pivots, and they are controlled at either end by steering gear, so that the car may-be taken with facility off the road, on to a branch, or *vice versa*. The fixed wheel-base—that of the driving wheels—is 4 feet, and the total wheel-base is 17 feet. The two cylinders are 6 inches in diameter, with a stroke of 9 inches; the coupled driving wheels are 27 inches in diameter, and the bogie wheels are 18 inches. The steam boilers, on Broadbent's system, are 25½ inches in diameter outside, and 6 feet long; the fire-box is 20½ inches diameter at the grate, giving 2·27 square feet of grate-area for each boiler.

An experimental steam car was constructed on this system, with 5-inch cylinders, and an 8-inch stoke; 27-inch driving wheels at 4-feet centres, and 19-inch bogie wheels, at 14-feet centres; 1·60 square feet of grate for each boiler; total weight, 8 tons, of which 5 tons was driving weight. It was publicly tried in May, 1876; and it is reported that the car ran easily on a circular line of 35 feet radius, to a gauge of 4 feet 8½ inches, with a pressure of 90 lbs. per square inch in the boiler, cutting off at 5-8ths of the stroke; though it was necessary to get up the pressure to 120 lbs.

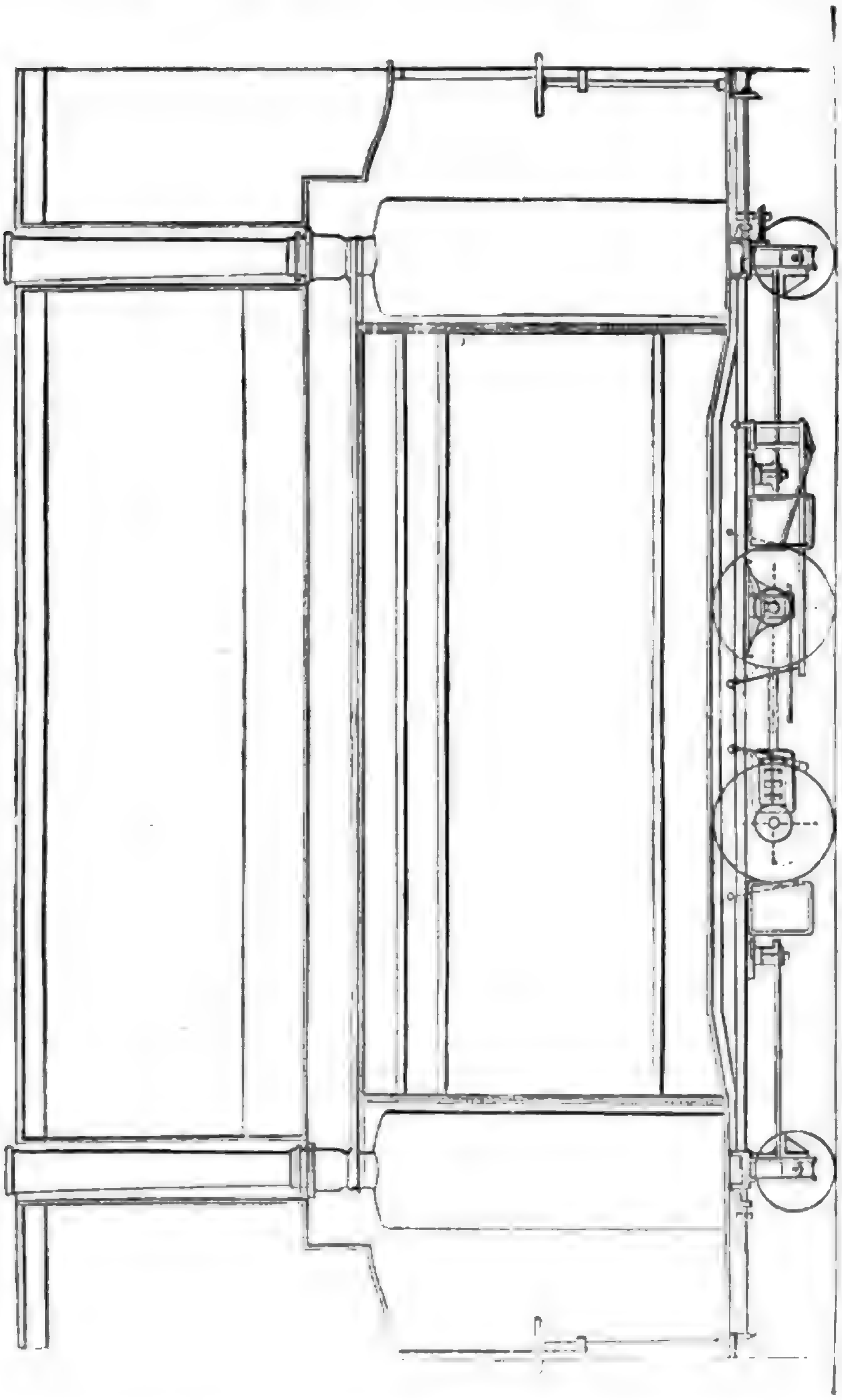

FIG. 304. Bissell Bogie Steam Car, by Mr. Edward Perrett, 1876. Scale $\frac{1}{48}$.

per square inch before starting again. With a pressure of 120 lbs. the car could start on an incline of 1 in 30.

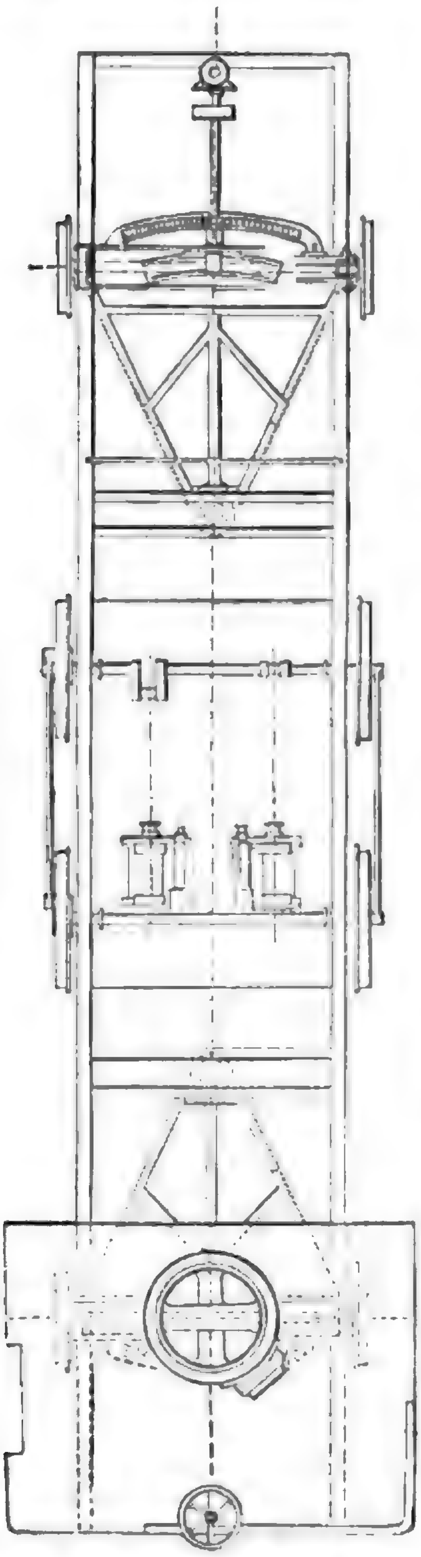

FIG. 305. Mr. Perrett's Steam Car. Plan. Scale $\frac{1}{48}$.

A car of this type, Fig. 306, was constructed by Messrs. Manlove, Alliott, Fryer & Co., Nottingham, for the Dublin and Lucan Tramway. The cylinders are 7 inches in diameter, with a stroke of 9 inches, and four coupled 27-inch wheels, 4½ feet apart between centres. The total wheel-base, including the Bissell trucks, one at each end, is 17½ feet. The car in working order, without passengers, weighs 9 tons. A series of tests of this car were made on an endless tramway, 3 feet in gauge, a quarter of a mile in length, on the premises of Messrs. Manlove & Co., to prove the amount of the gross resistance. Indicator-diagrams were taken from the engines, yielding the following results:—

On a straight line, with ascending gradients of 1 in 57 and 1 in 22, the indicator frictional resistances, after allowing for the resistance of gravity, were, at 4 miles per hour, at the rate of 35 lbs. and 36 lbs. per ton on the two gradients respectively; and at 8 miles per hour, 41 lbs. and 39 lbs. On a curve, of 60 feet radius, on a level, the resistances were 81 lbs. and 96 lbs.; going up an incline 1 in 41, they were 50 lbs. and 75 lbs.; up 1 in 33, they were 65 lbs. and 84 lbs. per ton. The mean results may be taken thus:—

Steam car.	4 miles per hour.	8 miles per hour.
Straight line, frictional resistance .	36 lbs. per ton	42 lbs. per ton.
Curve, 60 feet radius, frictional resistance	63 lbs. ,,	85 lbs. ,,

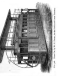

Fig. 306.—Steam Car, by Mr. E. Perrett, for the Dublin and Lucan Tramway.

Here it appears that the resistance on a curve of 60 feet radius is, in round numbers, double the resistance on a straight line. This result compares unfavourably with the result of trials for the trational resistance of a passenger-car on the same line of way, page 405, where it was deduced that the straight-line resistance of a car was little more than doubled even on a curve of 22 feet radius. It is probable that the greater resistance of this steam-car is attributable not alone to the working of the propelling machinery as such; but also to the spread and the arrangement of the wheel system. The fuel—gas coke—for a run of 6 miles, at a speed of 8 miles per hour, was consumed at the rate of 17 lbs. per mile, or nearly 2 lbs. per ton-gross per mile. Of course, the great and unequal resistance of inclines and curves contributed to the causing of so considerable a consumption of fuel.

This steam car was set to work on the Dublin and Lucan Tramway, on June 6, 1881, working between Dublin and Chapelizod, a length of two miles, making 13 double trips, equal to 52 miles per day. The car, weighing 9 tons empty, weighs with 1½ tons of passengers, the average load 10½ tons-gross. The fuel consumed per day is 6 cwt. of gas coke, including the fuel consumed for getting up steam, equivalent to 1·3 lb. per ton-gross per mile. This comparatively high rate of consumption may be accounted for, to some extent at least, by the unfavourable conditions under which the work was done. The car makes but one double-trip or 4-mile run in each hour. In fact, the 2-mile trip was made in 10 minutes, and the car was at rest for forty minutes in each hour.

BROWN.

Mr. A. Brown, of Winterthur (Switzerland), designed a steam car for tramways, on the principle of Mr. R. F. Fairlie's double-bogie railway steam-carriage. An illustration of his original design was published in *Engineering*, for March 31, 1876. He constructed a steam-car on the same system, on a somewhat modified design, which was put to work, in 1877, on the Lausanne and Echellens Branch Railway—a "Chemin de Fer Régional"—for local traffic, constructed to a gauge of 1 metre, 8·86 miles in length, and laid on the common road, which inclines upwards from Lausanne to Echellens. The ruling inclines are heavy; they are as follows:—

		Yards.
1 in 28	for	545
1 in 40	„	578
1 in 31	„	236
1 in 25	„	655
		2,014

The minimum radius is 100 metres, or 330 feet; in stations, it is 60 metres, or 200 feet.

The car, Figs. 307, 308 and 309, is supported at each end by a four-wheel swivelling bogie. The engine with its boiler complete is supported on one of the bogies, the wheels of which are coupled, and constitute the driving-wheels; the locomotive is lodged in one end of the car, where it is wholly masked by the surrounding portion of the car, and is free to revolve on its axis.

The cylinders are horizontal, and are above the foot-plate. The valve-chests are below the cylinders, and so these are kept clear of condensation-water. The piston-rods each work a vertical rocking beam, from the lower ends of which the wheels are driven by connecting-rods. This arrangement is employed for the sake of keeping most of the working machinery out of the way of dust. The valve-gear consists of a combination of levers and rods worked off the connecting-rod,—in which excentrics and straps are dispensed with.

The main framing of the car is of joist iron, at such a level that the floor of the car is only 19 inches above the level of the rails. The car is divided into three portions—the saloon furnished with longitudinal seats, upholstered, for 24 passengers; the pavilion at the hind end, over the hind bogie, as a smoking department for 7 passengers; and the upper story, or imperial, to which a staircase leads from the pavilion, with seats for 30 passengers. Thus accommodation is provided for 61 passengers in all.

The following are the leading dimensions of the steam car:—

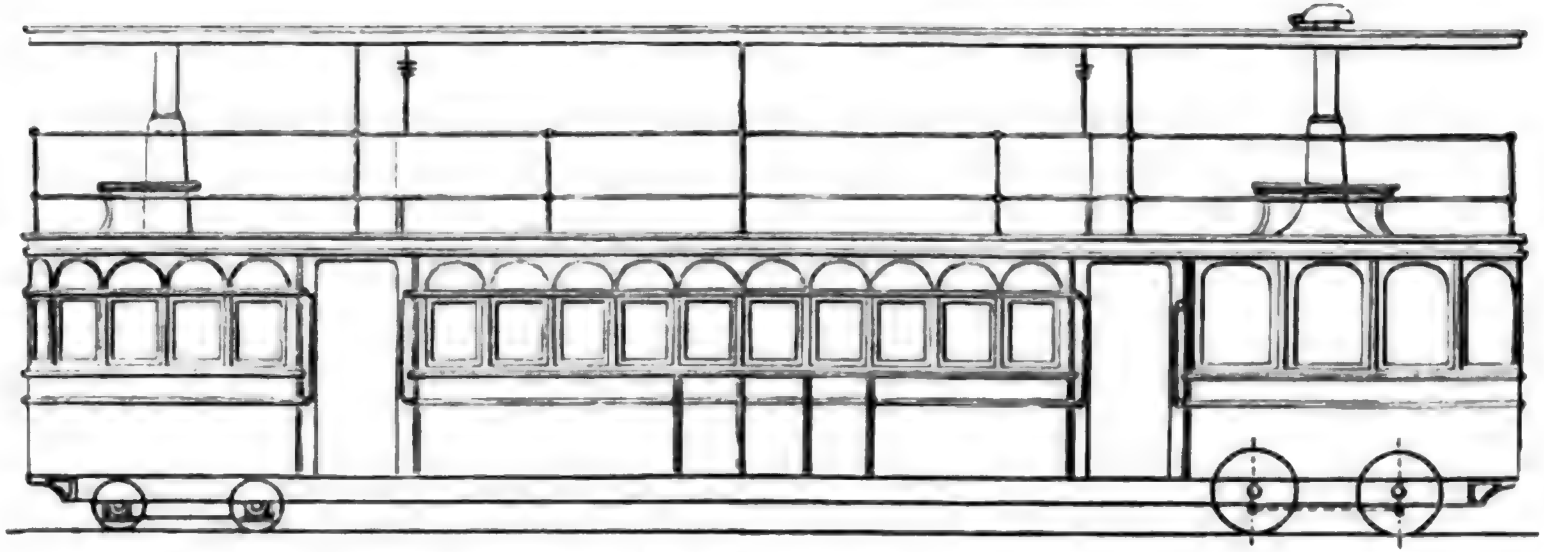

FIG. 307. Double-Bogie Steam Car, by Mr. Brown, 1877. Elevation. Scale $\frac{1}{96}$.

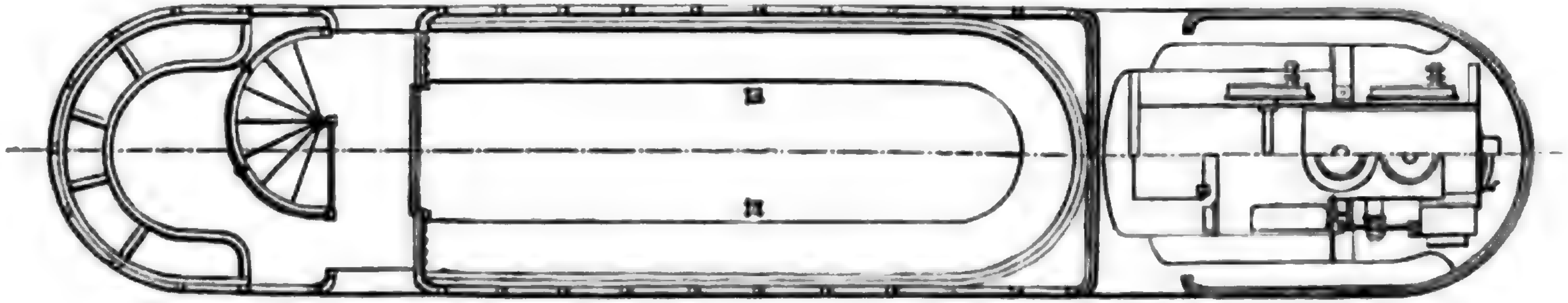

FIG. 308. Mr. Brown's Steam Car. Plan.

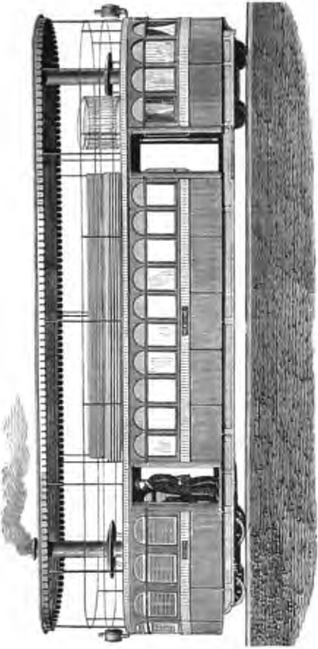

FIG. 309. Steam Car, by Mr. Brown, Winterthur.

Car :—	Feet.	Inches.
Length over all	42	3½
Extreme breadth	7	9½
Height	14	1
Diameter of bogie-wheels of car	1	5¾
Wheel-base of bogie	4	0
Distance between centres of bogies	30	4¾
Engine :—		
Diameter of steam-cylinders	0	6¼
Length of stroke	1	0
Diameter of coupled wheels	2	3½
Length of wheel-base	4	1
Diameter of boiler	2	3½
Length of flue-tubes	4	7

	Square feet.
Area of fire-grate	2·35
Heating surface :—Fire-box	20
Tubes	130
Total	150
Pressure of steam in boiler (per square inch)	180 lbs.
Capacity of water-tanks	130 gallons.
Do. coal-bunkers	5 cwt.

Weight :—	Tons.
Engine, empty	5
Do. in working order	6
Car, empty	6½
Engine and empty car	11½
Total weight in working order, with 61 passengers, and luggage	16
Driving weight, when the car is fully loaded	10
Net weight of engine and car, in working order, per passenger	3·77 cwt.
Maximum load per driving axle	5 "
do. do. per free axle	3 "

On Sundays, 600 persons have been carried in eight trips, or, 75 passengers at a time. The greatest number taken at a time was 120. It is stated that the ordinary speed was about

9 miles per hour, but speeds of about 19 miles per hour have been attained on a level. The car may be stopped on the steepest gradients within from 16 to 20 feet. It is reported that the engine has never slipped her wheels, even in the most unfavourable weather—in snow, ice, or fog. The fuel, Saarbruck coal, has been consumed at the rate of 11½ lbs. per mile, or ·72 lb. per ton-gross per mile. The daily expenses for working the steam-car at Lausanne, doing 29 miles per day, have been as follows:—

	Per day. s.	d.
1 engine-driver	6	4
1 stoker	2	9½
1 conductor	3	2
Coal (3 cwt.)	4	9
Grease, oil, &c.	1	7
	18	7½

Or, 7·7d. per mile-run.

It is stated that if the steam-car were worked over a nearly level road, it could easily make 80 miles a day, at a daily expense of 25s., equivalent to 3¾d. per mile run. But in this charge there is no element for maintenance. The price of the steam-car is £1,000.*

Independent engines of the same type have been constructed by Messrs. R. and W. Hawthorn, as shown in Fig. 310. The cylinders are 5½ inches in diameter, and have 11¾ inches of stroke. The wheels are made from 2 feet to 2 feet 4 inches in diameter, on a wheel-base of 5 feet. The pressure in the boiler is 220 lbs. The steam is condensed in tubes placed overhead. The weight of the engine with coal and water is 6¾ tons.

Engines of this class have been working at Strasburg, at a cost of about 5d. per mile-run. At Hamburg the cost was 4½d. per mile-run. The engines have also been at work on the Sunderland tramways, where they can take, when required, two cars loaded with goods, weighing 6½ tons-gross, up gradients of 1 in 25 and

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* The above particulars of the steam-car are taken from *Engineering*, for August 10, 1877, p. 108.

1 in 18. The condensing power is increased in the more recently-made engines, with a view to reducing the back pressure and suppressing all the exhaust steam, even on the severest inclines.

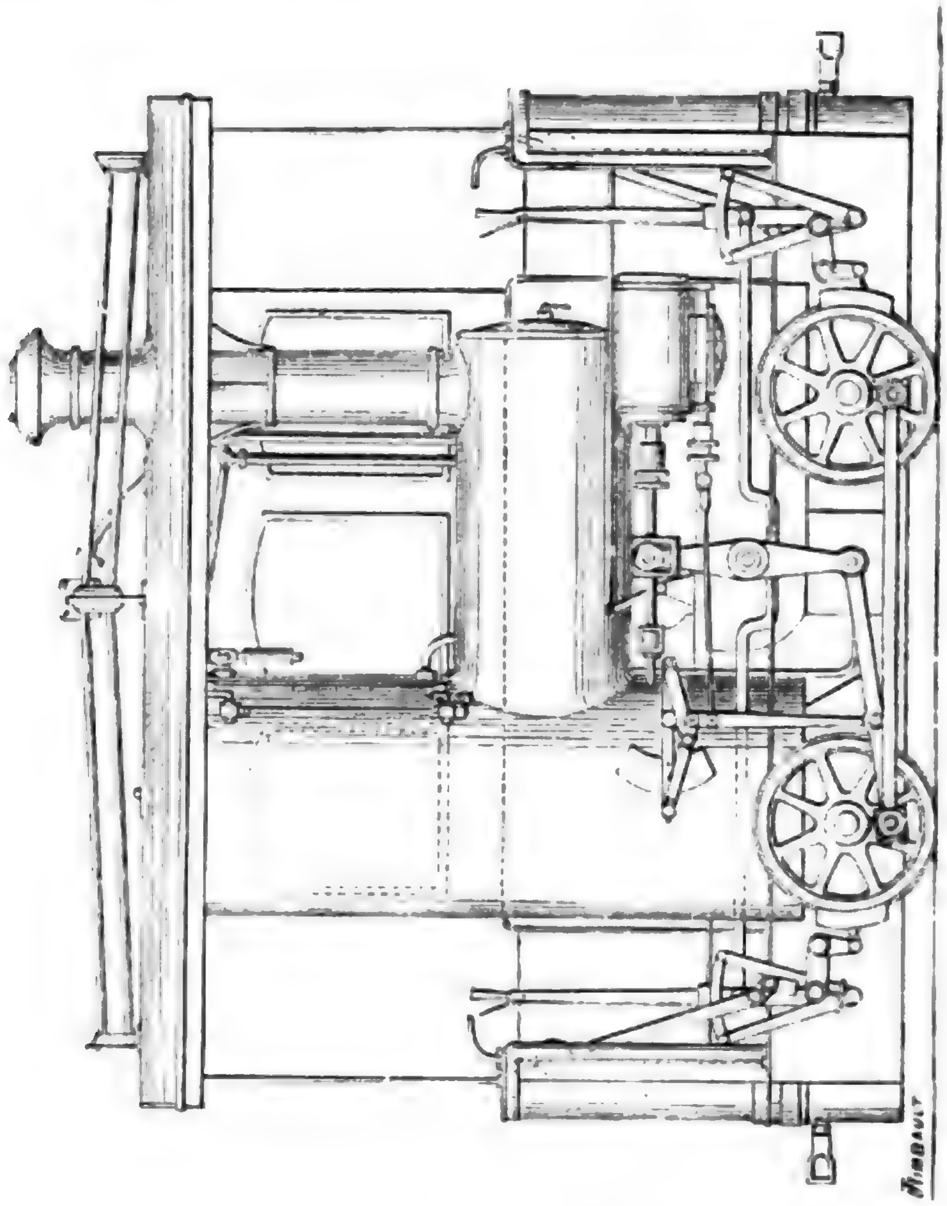

FIG. 310. Tramway Locomotive by Messrs. R. & W. Hawthorn. Scale $\frac{1}{40}$.

ROWAN.

Mr. W. R. Rowan, of Copenhagen, designed a steam-car for tramways, Fig. 311, resembling Mr. Fairlie's steam carriage, and Mr. Brown's car, in general arrangement.

But Mr. Rowan, not recognising the principle of Mr. Fairlie's steam carriage, reverted to the American railway carriage, or car, for his prototype, "the body resting on two bogies or under-carriages"; and "with a view of affording a suitable place in which the engine may stand," he naïvely explained that "the pin of one of the bogies is made hollow and enlarged to several feet in diameter, instead of being a mere pin of metal, and in this hollow pin is fixed the engine, which acts directly upon the bogie-wheels underneath, and thus sets the whole carriage in motion. It is evident that the enlargement of the bogie-pin will not affect the revolving movement of the carriage body upon it; nor will the engine in this position interfere with the arrangements for ascending or descending to or from the upper seats of the car at either end." *

There need not be any doubt of the feasibility of the system. It was amply tested on a working scale by Mr. Fairlie many years ago. The engine may be readily detachable from the body of the car, when required, by the aid of a temporary crutch lowered to support the free end of the car.

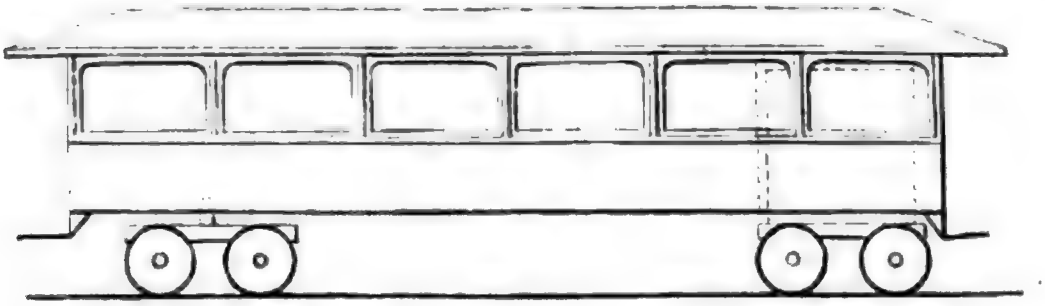

FIG. 311. Double-Bogie Steam Car, by Mr. W. R. Rowan, 1877. Scale $\frac{1}{114}$.

Mr. Rowan condensed the exhaust steam by surface-condensation in a sheet-iron chamber, which is traversed by a number of tubes, either flat or round, from end to end. The steam was exhausted into the chamber surrounding the tubes; and was condensed by currents of cold air from a fan driven through the tubes on its way to the furnace. By this means, the air might be heated to 190° or 200° F., whilst the steam was effectively condensed, and the condensation water was pumped again into the

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* *The Employment of Mechanical Motors on Tramways.* By W. R. Rowan, C.E., 1877.

boiler. Mr. Rowan considered that from 1,000 to 2,000 square feet of condensing surface was sufficient for an engine of from 15 to 25 horse-power.

The steam-car last constructed by Mr. Rowan was 32 feet long over all, built of teak, excepting the side-soles and the roof. It was made to seat 60 passengers inside and outside. The only entrance is at the hinder end. The engine was capable of working to 18 horse-power, with a pressure in the boiler of 150 lbs. per square inch. The cars easily passed on curves of 45 feet radius, and could surmount a gradient of 1 in 20. The total weight of the car and engine was 5 tons. Mr. Rowan gives the following comparative statement of the "working elements" of a horse-car, a car drawn by a separate engine, and his steam-car :—

COMPARATIVE "WORKING ELEMENTS" FOR HORSE-POWER AND STEAM-POWER, ON TRAMWAYS.

Working elements.	Horse-car.	Car drawn by a separate engine.	Steam-car.
Number of passengers .	40	40	60
Do. servants . .	2	2	2
Length of street occupied .	35 feet	35 feet	32 feet
Gross weight, including passengers	5½ tons	9½ tons	9½ tons
Weight, without passengers	2½ ,,	6½ ,,	5 ,,
Maximum weight on any wheel, with gross load .	1·375 ,,	1·375 ,,	1·50 ,,
Maximum weight on any wheel, without load . .	·625 ,,	1·000 ,,	1·00 ,,
Dead weight per passenger	1¼ cwt.	3 cwt.	1⅔ cwt.
Greatest weight on driving-wheels, with full load .	—	4 tons	6 tons
Greatest weight on driving-wheels, without load .	—	4 ,,	4 ,,
Horse-power for haulage .	2 h.p.	18 h.p.	18 h.p.
Steepest working gradient for long runs . . .	1 in 80	1 in 40	1 in 20

On the results of the trials of his steam-car, Mr. Rowan based an estimate of the comparative cost of working tramway traffic on his system, and by ordinary horse-traction, assuming that the saving in tear and wear of stock on his system is balanced by the increase in the wear of the road, and leaving, therefore, these causes of expenditure out of the account:—

(1) *Steam-cars.—Daily Expenses.*

	Kroner.		s.	d.
1 engineman	7·50	or	8	3½
⅐ reserve do	1·08	,,	1	3
¼ cleaner	1·12	,,	1	3½
Coke	9·00	,,	10	0
Oil, tallow, waste, &c. . . .	1·50	,,	1	8
Sundry petty expenses . . .	2·30	,,	2	6
	22·50	,,	25	0

Allowing a day's work of 12 Danish miles, or 56·16 English miles, the expenses are equivalent to 5·34d. per English mile, or to ·09d. per passenger per mile.

(2) *Horse-cars.—Daily Expenses.*

The cost for horse-power to the Copenhagen Tramway Company, in 1874, amounted to 2·10 kroner per Danish mile, or 6d. per English mile; for a car seated for 40 passengers, equivalent to ·15d. per passenger per mile.

From these statements, it appears that the expense of working with the steam-car would be absolutely less by ·66d., or 12½ per cent., and that per passenger it would be less by 40 per cent., supposing, of course, that full loads were taken in each case.

More recently (1891—93), Rowan's steam-car has been in use on a line at Stockholm, having gradients of 7 per cent., or 1 in 14. It contains a 6-ton motor working up to 14 atmospheres (200 lbs. per square inch), and carries from 30 to 50 passengers. The total weight available for adhesion is 11 tons, and develops a tractive force of 1,000 kilogrammes, equal, at 8 kilometres per hour, to 30 horse-power. The first cost of such a steam-car is about £800 at the works. The Rowan steam-car is also used on seven other light railways in Sweden, and on suburban lines at Copenhagen, Berlin, Saarbrücken, Moscow, Paris, Tours, Lyons, and Marseilles. These lines are for the most part level.

CHAPTER III.

CALCULATION OF STEAM LOCOMOTIVE POWER ON TRAMWAYS.

When the effective mean pressure in the cylinders of a locomotive, of which there are usually two, is known, the tractive force at the rails is readily estimated in terms of that force, and the dimensions of the machinery.

Take the case, nearly universal, of two cylinders connected directly to the driving-wheels and their axle. The pressure developed in the pair of cylinders is thus expressed by the equivalent pressure or tractive force, as at the rails :—

$$\mathrm{T} = \frac{d^2 \, \mathrm{L} \, p}{\mathrm{D}} \quad . \quad . \quad . \quad . \quad (1)$$

Reversely, the effective mean pressure on the pistons, equivalent to a given tractive force at the rails, is expressed by the formula—

$$p = \frac{\mathrm{D} \; \mathrm{T}}{d^2 \, \mathrm{L}} \quad . \quad . \quad . \quad . \quad (2)$$

d = the diameter of the cylinders, in inches.
L = the length of the stroke, in inches.
D = the diameter of the driving-wheels, in inches.
p = the effective mean pressure on the pistons, in lbs. per square inch.
T = the equivalent tractive force at the rails, in lbs.

That is to say:—*To find the tractive force*—Multiply the square of the diameter of the pistons, in inches, by the length of the stroke, in inches, and by the effective mean pressure on the pistons in pounds per square inch; and divide the product by the diameter of the driving-wheels, in inches. The quotient is the equivalent force, as tractive force, at the rails, in pounds.

To find the effective mean pressure.—Multiply the diameter of the driving-wheel, in inches, by the total equivalent tractive force at the rails, in pounds; and divide the product by the square of the diameter of the cylinders, in inches, and by the length of stroke, in inches. The quotient is the effective mean pressure in pounds per square inch.

It is understood, of course, that so much of the power developed in the cylinders, as is necessary to overcome the resistance of the machinery of the engine, is intercepted and consumed; and that only the balance of the power is available for tractional action at the rails, and there exerted. But, for the sake of reducing, for purposes of estimation, all the resistances of the engine, as well as those of the car, to one standard for measurement, the whole of the steam-power in the cylinders, as measurable by the indicator, is reduced to an equivalent tractional force at the rail.

EFFECTIVE MEAN PRESSURES IN THE CYLINDERS.

Period of admission in parts of the stroke.	Effective mean pressure in parts of the maximum pressure.	Period of admission, in fractions of the stroke.	Effective mean pressure, in parts of maximum pressure.
Per cent.	Per cent.		
10	15	1-10th	1-7th fully
12½	20	1-8th	1-5th
15	24	1-6th	1-4th
17½	28		
20	32	1-5th	1-3rd
25	40	1-4th	1-⅖th
30	46	1-3rd	1-2nd
35	52		
40	57	—	—
45	62	—	—
50	67	1-2nd	2-3rds
55	72	—	—
60	77	—	—
65	81	2-3rds	4-5ths
70	85	—	—
75	89	3-4ths	9-10ths

The effective mean pressure in ordinary steam-cylinders, non condensing, worked by ordinary valves and link-motion, is given in the annexed table, for various periods of admission, of from 10 per cent. to 75 per cent. of the stroke, and for maximum pressures in the cylinder of from 60 lbs. per square inch to 150 lbs. per square inch.*

The proportion of the adhesion-weight, or driving-weight, of the engine, which measures the force of adhesion, available for traction, is very variable—from one-fifth in dry weather, according to the author's experiments on the adhesion upon railways, to one-ninth in damp weather, when the rails may be slippery. To keep within the limits of one-ninth, in the proportioning of engines to their work, ensures the working the engine in all states of the weather; but a larger fraction may wisely be assumed for the purposes of general estimates, particularly as the aid of dry sand dropped on the rails may be invoked, when necessary, for the increase of the adhesive force. A fraction of one-eighth may safely be adopted.

The influence of gradients on the resistance to traction, is easily calculated by multiplying the gross load by the fraction which expresses the rate of inclination. The product is the amount by which the resistance is increased in ascending a given gradient; or, on the contrary, reduced in descending the gradient. To exemplify the effect of an ascending gradient in increasing the resistance, and reducing the available gross load, take such gradients as are equivalent to 30 lbs. per ton, and it multiplies thus:—

Gradient.	Resistance due to gravity.
1 in 75 or 1·33 per cent.	30 lbs. per ton
1 in 37 „ 2·70 „	60 lbs. „
1 in 25 „ 4·00 „	90 lbs. „
1 in 18½ „ 5·40 „	120 lbs. „
1 in 15 „ 6·66 „	150 lbs. „

Taking, as before adopted, a resistance of 30 lbs. per ton, as the normal resistance on a level, the resistance is 30 lbs. more, or is doubled, for an ascending gradient of 1 in 75; and the gross load that can be drawn up the incline, by a given force of traction, is halved:—

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* This table is copied from the author's work on *Railway Machinery*, 1855, page 116.

On a level the available gross load is as		1
On an incline of	1 in 75, it is as	½
,,	1 in 37 ,,	⅓
,,	1 in 25 ,,	¼
,,	1 in 18½ ,,	⅕
,,	1 in 15 ,,	⅙

As the tramway engine traverses the line in both directions, the work done on each section of the line, whether level or inclined, may, for general purposes, be taken, when averaged for both directions, to be the same as the work done on a level; and it may be assumed that the average period of admission of the steam to the cylinder is 50 per cent. or half-stroke. The average initial pressure in the cylinder may therefore be assumed as that due to the effective mean pressure that is equivalent to the resistance on a level.

From the foregoing rules and data, the quantity of steam consumed may be calculated for a given distance—per mile-run, for instance; and thence,—in terms of the relative volume of steam,—the quantity of water evaporated, and the quantity of fuel to be consumed. The volume of steam consumed for a stroke of one piston is half the capacity of one cylinder; and there are four halves, or two cylinders, full of steam, consumed for one turn of the driving-axle; or,

Steam consumed per turn in cubic inches,

$$= \cdot 7854\, d^2 \times \text{L} \times 2;$$

$$= 1\cdot 5708\, d^2\, \text{L} \qquad (a)$$

d = the diameter of the piston, in inches.
L = the length of the stroke, in inches.
D = the diameter of the driving-wheel, in feet.
S = the volume of steam consumed, in cubic feet, per mile.

The quantity of steam, in cubic inches, consumed per mile is equal to the quantity (*a*), multiplied by the number of turns made in a mile, or by $\frac{5280 \text{ feet}}{3{\cdot}1416 \text{ D}}$; and if this product be divided by 1728, the quotient is the number of cubic feet consumed per mile. But an addition is to be made for the usual proportion of steam condensed in the cylinder—12 per cent. of the indicated quantity. when the steam is cut off at half-stroke—and the total quantity of steam actually consumed is as follows:—

$$\text{S} = \frac{1{\cdot}5708\, d^2\, \text{L} \times 5280}{1728 \times 3{\cdot}1416\, \text{D}} \times \frac{112}{100}; \text{ or,}$$

$$\text{S} = \frac{1{\cdot}71\, d^2\, \text{L}}{\text{D}} \quad . \quad . \quad . \quad . \quad (3)$$

That is to say:—*To find the average volume of steam actually consumed per mile, cut off at an average of half the stroke*—Multiply the square of the diameter of the cylinder in inches by the length of the stroke in inches, and by 1·71; and divide the product by the diameter of the driving-wheels in feet. The quotient is the average volume of steam consumed per mile.

The equivalent quantity of water required to be evaporated to form the steam thus calculated is found by dividing the volume of the steam by its relative volume; that is, its volume compared with that of the water of which it consists. Thus:—

$$\text{W} = \frac{1{\cdot}71\, d^2\, \text{L}}{\text{D} \times \text{rel. vol.}} \quad . \quad . \quad . \quad . \quad (4)$$

W = the average volume of water evaporated, in cubic feet, per mile.

To express the volume of the water in gallons, multiply the value (4) by 6·2355, the number of gallons in a cubic foot. Thus:—

$$\text{W} = \frac{1{\cdot}71 \times 6{\cdot}2355 \times d^2\, \text{L}}{\text{D} \times \text{rel. vol.}}; \text{ or}$$

$$\text{W} = \frac{10{\cdot}7\, d^2\, \text{L}}{\text{D} \times \text{rel. vol.}} \quad . \quad . \quad . \quad . \quad (5)$$

W = the average volume of water evaporated, in gallons, per mile.

That is to say:—*To find the average volume of water as steam consumed per mile, cut off at an average of half the stroke*—1. In CUBIC FEET. Multiply the square of the diameter of the cylinders in inches, by the length of the stroke in inches, and by 1·71; and divide the product by the diameter of the driving-wheels in feet, and by the relative volume of the steam. The quotient is the volume of water in cubic feet.

2. In GALLONS. Perform the same calculation as the preceding, except that the multiplier 10·7 is to be employed instead of 1·71. The quotient is the volume in gallons.

To facilitate such calculations, particulars of the volume and density of saturated steam are given in the following table, abstracted from the author's larger table.*

DENSITY AND VOLUME OF SATURATED STEAM.

Pressure per square inch above the atmosphere.	Density, or weight of one cubic foot.	Volume of one pound of steam.	Relative volume, or cubic feet of steam from one cubic foot of water.
lbs.	lbs.	Cubic feet.	Relative volume.
0	·0380	26·36	1,642
5	·0507	19·72	1,229
10	·0625	15·99	996
15	·0743	13·46	838
20	·0858	11·65	726
22	·0905	11·04	688
24	·0952	10·51	655
26	·0996	10·03	625
28	·1042	9·59	598
30	·1089	9·18	572
32	·1133	8·82	550
34	·1179	8·48	529
36	·1224	8·17	509
38	·1269	7·88	491
40	·1314	7·61	474
42	·1364	7·36	458
44	·1403	7·12	444
46	·1447	6·90	430
48	·1493	6·70	417

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* See *A Manual of Rules, Tables, and Data for Mechanical Engineers*, 1877, page 387.

DENSITY AND VOLUME OF SATURATED STEAM—*continued.*

Pressure per square inch above the atmosphere.	Density, or weight of one cubic foot.	Volume of one pound of steam.	Relative volume, or cubic feet of steam from one cubic foot of water.
lbs.	lbs.	Cubic feet.	Relative volume.
50	·1538	6·49	405
52	·1583	6·32	393
54	·1627	6·15	383
56	·1670	5·99	373
58	·1714	5·83	363
60	·1759	5·68	353
62	·1804	5·54	345
64	·1848	5·41	337
66	·1891	5·29	329
68	·1935	5·17	321
70	·1980	5·05	314
72	·2024	4·94	308
74	·2067	4·84	301
76	·2111	4·74	295
78	·2155	4·64	289
80	·2198	4·55	283
82	·2241	4·46	278
84	·2285	4·37	272
86	·2329	4·29	267
88	·2351	4·25	265
90	·2414	4·14	257
92	·2456	4·07	253
94	·2499	4·00	249
96	·2543	3·93	245
98	·2586	3·86	241
100	·2628	3·80	237
105	·2738	3·65	227
110	·2845	3·51	219
115	·2955	3·38	211
120	·3060	3·27	203

When the ordinary evaporative performance of the fuel used in the boiler is known:—the quantity of water evaporated per pound of fuel, or the quantity of fuel required to evaporate a cubic foot of water—the average quantity of fuel consumed per mile is easily estimated, from the quantity of water consumed. The evaporative performance above defined is usually expressed in terms of the weight of water evaporated per pound of fuel. The volume of water, taken as cold water, in cubic feet per mile, may be multiplied by 62½, to give the weight of water in pounds; or the volume, if expressed in gallons, is to be multiplied by 10, to give the weight of water in pounds. The product so found is divided by the evaporative ratio of the fuel, and the quotient is the average quantity of fuel consumed per mile.

To exemplify the application of the foregoing rules, with the tables and the deductions, take the locomotives constructed by Messrs. Merryweather & Sons, for the tramways of Paris (Reseau Sud). The cylinders are 6 inches in diameter, with a stroke of 9 inches; the driving-wheels are 2 feet in diameter. The weight of the engine in full working condition is 4 tons, and it draws a loaded car, say, 7 tons in weight. The gross weight to be drawn is 11 tons; and the total resistance, on the level, at a uniform speed, at the rate of 30 lbs. per ton, is (11 × 30 =) 330 lbs. at the rail. To find the equivalent pressure on the pistons—the effective mean pressure, p, by formula (2):—

$$p = \frac{\text{D T}}{d^2 \text{ L}} = \frac{24 \times 330}{36 \times 9} = 24{\cdot}4 \text{ lbs. per square inch.}$$

By the table, to produce an effective mean pressure of 24·4 lbs. per square inch, the initial pressures for different periods of admission, or cut-offs, are as follows:—

For a Uniform Speed.

				Per square inch.
Cutting off at	⅕th,	the initial pressure is	24·4 lbs. × 3	= 73 lbs.
Do.	¼th	do.	24·4 lbs. × 2½	= 61 lbs.
Do.	⅓rd	do.	24·4 lbs. × 2	= 49 lbs.

For starting the train on the level, allow four times the tractive force, or four times the effective mean pressure required for a uniform speed—in this case, 1,320 lbs. traction, or 98 lbs. per square inch in the cylinders; then—

For Starting the Train. Per square inch.

Cutting off at ¾ the initial pressure is 98 lbs. $\times \frac{10}{9} =$ 109 lbs.

Do. ⅔ do. 98 lbs. $\times \frac{5}{4} =$ 122 lbs.

If the pressure in the boiler be 120 lbs. per square inch, it is sufficient for the exertion of the extreme tractive forces above assumed.

But, suppose that the rate of the ruling gradient of the tramway amounts to 1 in 25. For the same tractional force, the gross load that can be taken up the line is, by the statement, page 495, reduced to one-fourth. To take up the same load, therefore, as on the level, the effective mean pressure in the cylinder should be four times as much as on the level, so that four times the tractive force may be exerted. That is, instead of an effective mean pressure of 24½ lbs. per square inch, there must be 98 lbs. effective pressure, being the same as was assumed for starting the train on a level. For the exertion of this pressure, it has already been shown that the initial pressure in the cylinder would amount to 109 lbs. per square inch, supposing that the steam were admitted for three-fourths of the stroke, or to 122 lbs. for two-thirds of the stroke.

This example is sufficient to illustrate the wideness of the range of power that may be exerted by a tramway steam-locomotive.

To find, by formula (4) or (5), page 496, the average quantity of water actually consumed as steam per mile, supposing, as was assumed, that the average period of admission is half the stroke. To find, in the first place, the relative volume, which is a factor in the formula, the initial pressure in the cylinder is to be determined. For an effective mean pressure of 24½ lbs. per square inch, cutting off at half-stroke, the initial pressure is, by the table, page 497, (24½ lbs. $\times \frac{3}{2} =$) 37 lbs. per square inch above the atmosphere. By formula (4) or (5), page 496, for which $d = 6$, $L = 9$, $D = 2$, and the relative volume of steam of 37 lbs. effective pressure, is 500 :—

$$w = \frac{1{\cdot}71 \times 6^2 \times 9}{2 \times 500} = {\cdot}554 \text{ cubic feet;}$$

$$\text{or } w = \frac{10{\cdot}7 \times 6^2 \times 9}{2 \times 500} = 3{\cdot}47 \text{ gallons:}$$

the average quantity of water consumed per mile.

To estimate now the quantity of fuel—which is coke—consumed per mile by Messrs. Merryweather's engine, it may be assumed, in the absence of positive data, that 7 lbs. of water are evaporated per lb. of coke. Reducing, then, the volume of water, ·554 cubic feet, or 3·47 gallons, to pounds, and dividing the weight by 7—

$${\cdot}554 \times 62\tfrac{1}{2} = 34{\cdot}35 \text{ pounds; and } \frac{34{\cdot}35}{7} = 5 \text{ lbs.}$$

$$\text{or } 3{\cdot}47 \times 10 = 34{\cdot}70 \text{ pounds; and } \frac{34{\cdot}70}{7} = 5 \text{ lbs.}$$

—showing a consumption of coke at the rate of 5 lbs. per mile run by the engine, in drawing a gross load of 11 tons, including the weight of the engine. To this, of course, is to be added an allowance for getting up steam, and for contingent waste of steam and fuel—say 10 per cent.; making an addition of ½ lb. of coke per mile, and altogether 5½ lbs. of coke consumed per mile.

Thus, by a simple process, founded on general experimental data, the exact quantity of coke actually consumed by those engines, as working on the Paris tramways, is arrived at. They consume 250 kilogrammes, or 550 lbs. of coke for 100 miles run; which is equivalent to 5½ lbs. per mile, the same as has just been calculated.

The foregoing values for water and fuel give the following data:—

Average Consumption per Ton Gross per Mile-run.

½ pound of coke.
3·5 pounds of water.

CHAPTER IV.

FIRELESS TRAMWAY LOCOMOTIVES.

A BODY of water heated under pressure, spontaneously generates and disengages steam, when the pressure is permitted to fall. The temperature at the same time falls, according to the decline of the pressure; and the temperature and pressure correspond exactly as if steam were generated by the application of heat to the water under a given pressure.

The corresponding pressures and temperatures may be ascertained by referring to a table of the properties of saturated steam, and the quantity of steam that may be spontaneously generated during the fall of the temperature may be calculated with exactness. For example, suppose a pound of water, heated to the temperature of 445° F., necessarily under the corresponding total pressure, 400 lbs. per square inch, and cooled to the temperature 281° F., corresponding to the total pressure, 50 lbs. per square inch.* The quantity of heat disengaged is measurable by the fall of temperature (445° − 281° =) 164°, and for a pound of water the loss of heat is 164 units. The heat so disengaged is available for evaporating water—in fact, a portion of the heated water itself—into steam. Now, the total heats of the two steams are as follows:—

Total pressure.	Temperature.	Total heat in 1 lb. of steam from 0° F. Units (or degrees).	Difference.
400 lbs.	445°	1,249	804°
50 lbs.	281°	1,199	918°
(Mean) 225 lbs.	—	—	861°

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* See *Manual of Rules, Tables, and Data*, 1877, page 387.

The mean difference, or excess of heat in the steam above the sensible heat, is 861°, or 861 units for 1 lb. of steam; and as the quantity of heat disengaged by 1 lb. of water in falling from 445° to 281° is 164 units, there are required (861 ÷ 164 =) 5·25 lbs. of the heated water to supply heat sufficient to evaporate 1 lb. of the heated water. That is to say, out of 5·25 lbs. of heated water 1 lb. is evaporated "spontaneously." In round numbers, one-fifth of the heated water is evaporated during the fall of temperature from 445° to 281°. By a similar calculation, it is found that the proportional quantities of heated water evaporated in falling to the temperature 281°, and total pressure 50 lbs. per square inch, from other temperatures and pressures, are as follows:—

Falling to Total Final Pressure, 50 *lbs. per square inch.*

Total initial pressure in lbs. per square inch.	Initial temperature.	One pound of water evaporated in	
400 lbs.	445°	5·25	lbs. of heated water.
350 ,,	430°	5·82	,,
300 ,,	418°	6·35	,,
250 ,,	401°	7·31	,,
200 ,,	382°	8·74	,,
150 ,,	358°	11·60	,,
100 ,,	328°	19·20	,,

It may be said that, in round numbers, a fifth of the heated water is evaporated in falling from a total pressure of 400 lbs. per square inch to 50 lbs. per square inch, and that a ninth is evaporated in falling from 200 lbs. to 50 lbs. per square inch.

Without going further, it is obvious that between the limits of 400 lbs. and 200 lbs. initial pressure in the reservoir, worked down to 50 lbs., a quantity of water, in round numbers, from five to nine times the quantity of water that can be converted into steam, must be constantly carried on the engine:—a tax by which engines constructed on this principle—the principle of spontaneous evaporation—are unfitted for taking the place of ordinary steam-locomotives for work in the open air.

COCKERELL.

An instructive practical trial was made in June, 1874, by the Société J. Cockerell, of Seraing, in Belgium, with one of their locomotives of the class designed for indoor service.* The boiler was vertical, 6½ feet high, and had two transverse water-tubes in the fire-box; the chimney rose direct from the fire-box, passing upwards through the steam-space. The boiler was not clad on the lower half of it, nor on the top, which was 3 feet in diameter. There were two cylinders, 8 inches in diameter, with a 10-inch stroke; four coupled wheels, 24 inches in diameter, 5 feet apart between centres, to a gauge of 4 feet 11 inches. The total capacity of the boiler was 35 cubic feet. The weight in working order was 8¾ tons; say, with four or five men, 9 tons.

First Experiment.—The locomotive at rest in the open air. Twenty-five cubic feet of cold water was measured into the boiler. The fire was lit, and, in the course of 2¼ hours, steam was got up to 10 atmospheres effective. The water level rose 1·38 inches in the glass, corresponding to a dilatation of (1·38 × ·78 =) 1·076 cubic feet, or 1-33rd of the initial volume, passing from the temperature 54° F. to 365° F.

The fire was then extinguished, and the grate was withdrawn. The chimney was hermetically sealed at the upper end. The fire-door was simply closed; there was no closure for the ash-pan. The weather was fine, the temperature was 77° F. in the shade, and at 5 P.M. the locomotive was left to itself, when the initial effective pressure was 9·40 atmospheres.

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* *Annales Industrielles*, February 7, 1875, col. 175.

Locomotive at Rest. Initial Effective Pressure 9·40 *Atmospheres.*

Time elapsed.		Fall of pressures.	Fall of level.
h.	m.	Atmospheres.	Inches.
0	10 (5 P.M.)	0·00	0·00
0	15	1·30	0·39
0	30	2·40	0·67
0	45	3·40	0·91
1	0	4·15	1·10
1	15	4·80	1·26
1	30	5·35	1·38
1	45	5·80	1·50
2	0	6·20	1·61
2	15	6·60	1·73
2	30	6·95	1·81
2	45	7·30	1·93
3	0	7·60	2·05
3	15	7·85	2·21
4	15 (9.15 P.M.)	8·40	2·68
16	0 (9 A.M.)	9·40	3·27

At the commencement of the observations, when the effective pressure was 9·40 atmospheres, the boiler contained 24·07 cubic feet of water as at 54° F. At the time of the last observation, when the pressure had fallen to atmospheric pressure, and the boiler was cool enough to permit of the hand being laid upon it, the quantity of water, as at 54° F., contained in the boiler, only amounted to 22·54 cubic feet; showing an apparent loss of 1·53 cubic feet, in 16 hours, at joints or cocks, although no escape had been apparent. The provision against cooling was not considerable. The surface of the fire-box in free contact with air, amounted to 49 square feet; that of the chimney 3⅓ square feet. It may be noted that whilst the pressure fell rapidly at the commencement, it fell less rapidly as it became lower.

Second Experiment.—The locomotive, alone, was run to and fro upon a piece of railway 552 yards in length, consisting of two straight pieces connected by a slight curve. The line was nearly level; it had a slight gradient of about 1 in 400, at one end. It was in good order, but it contained several points and crossings.

Steam was got up to a pressure of upwards of 10 atmospheres effective, in 2½ hours after lighting the fire. The fire was then drawn, and the mouth of the chimney was hermetically sealed around the exhaust-pipe, which was prolonged upwards through the chimney. The circulation of cold air through the boiler was thus prevented. The fire-door was closed; but the ash-pan was left open. The cylinder-cocks were open for some time at starting, and the steam was cut off at 80 per cent. of the stroke. During the journey the steam was cut off at 60 or 70 per cent. During the last run, the maximum admission for steam was required, with the regulator wide open. Four or five men were carried on the engine.

There was a slight wind blowing, and to neutralise the circumstances of wind and gravity as far as possible, the engine was run to and fro several times. The effective pressure at the commencement amounted to 10·30 atmospheres; there were 24·91 cubic feet of water, as at 54° F., in the boiler; and of steam 10 cubic feet. At the end of the last return trip, the effective pressure was 1 atmosphere; there was 21·66 cubic feet of water, as at 54° F., and 13·29 cubic feet of steam. The total fall of pressure was, therefore, 9 atmospheres, and the quantity of water consumed was 3·25 cubic feet. The following are the results of the experiment:—

Locomotive alone in Motion. Initial Effective Pressure, 10·30 *Atmospheres.*

Time elapsed.	Total distance run.	Average speed each trip.	Fall of pressure.
Minutes.	Yards.	Miles per hour.	Atmospheres.
0	0	0	0·0
3	552	6·31	2·30
5	1,104	9·44	3·80
7	1,656	9·44	5·05
9	2,208	9·44	6·10
12	2,760	6·31	7·05
15	3,312	6·31	7·90
18	3,864	6·31	8·05
23	4,416	3·78	9·30

At the end of the last run, the engine was pushed home by two men for a few yards.

The total distance run was 2·51 miles, and the water consumed was at the rate of (3·25 ÷ 2·51 =) 1·30 cubic feet, or 87 lbs., per mile. Allowing an evaporative power of 7 lbs. of water per lb. of fuel, the fuel consumed, if the steam had been generated on the journey, would have amounted to (87 ÷ 7 =) 12½ lbs. per mile; equivalent to (12½ ÷ 9 =) 1·40 lbs. per ton gross per mile.

It was observed that, though very little water or priming appeared with the exhaust-steam when the pressure was high, there was a notable increase of priming towards the end of the trial, when the pressure had fallen.

Third experiment.—The locomotive with one waggon was run to and fro on the experimental line. Immediately after the last experiment, steam was again got up in the engine. In 1 hour 10 minutes, an effective pressure of 10 atmospheres was got up; whilst the boiler was refilled. The fire was withdrawn, and the chimney was sealed, as before. An ordinary waggon, in ordinary condition, was coupled to the locomotive. The waggon had 4 wheels, 3 feet 3 inches in diameter, at 9 feet 9 inches apart between the axles. It was fitted with a screw-brake, and its weight with a small load was 8·80 tons. The gross weight drawn was as follows:—

	Tons.
Locomotive	9
Waggon	8·80
	17·80

The initial effective pressure in the boiler was 10½ atmospheres, and the final pressure was 2·30 atmospheres. There were 24·91 cubic feet of water in the boiler at the commencement of the trial, and 21·91 cubic feet at the termination, after six trips were made; showing that 3 cubic feet of water were consumed on the trial.

Locomotive and One Waggon in Motion. Initial Effective Pressure, 10·50 *Atmospheres.*

Time elapsed.	Total distance run.	Average speed each trip.	Fall of pressure
Minutes.	Yards.	Miles per hour.	Atmospheres.
0	0	0	0
2·5	552	7·53	1·85
5	1,104	7·53	3·50
7·5	1,656	7·53	5·00
9·5	2,208	9·44	6·25
12·5	2,760	6·31	7·30
15·5	3,312	6·31	8·20

The total distance run was 1·90 miles, and the water was consumed at the rate of (3 ÷ 1·90 =) 1·58 cubic feet, or 99 lbs. per mile; or, calculating as before, 14 lbs. of fuel per mile, equivalent to (14 ÷ 17·80 =) 0·79 lb. per ton gross per mile.

The performance of the engine was more economical in the last experiment; for the addition of the waggon caused but a small addition to the quantity of water consumed. The comparative economy of steam in the third experiment is due to the higher pressure necessarily employed in the cylinders to overcome the resistance of the greater weight to be drawn, and to the greater efficiency of the steam in consequence, against the constant resistance of the atmosphere. The following data are derived from the results of the third experiment:—

Average Consumption per Ton Gross per Mile-Run.

⅕ of a pound of coke [in heating up the water].
5½ pounds of water.

The distance run for these rates of consumption was 2 miles, on a line of railway practically level.

These results do not compare advantageously with those of the Merryweather locomotive, page 501, where it appears that this engine consumed only ½ lb. of coke per ton gross per mile, against the resistance of a tramway. and on inclines; whereas in the experiment with heated water, ⅘ lb. of coke is the equivalent of the quantity of water consumed on a railway nearly level.

* * *

FRANCQ.

M. Léon Francq, in 1875, patented a fireless locomotive containing some improvements on Dr. Lamm's engine. The reservoir was 3 feet 9 inches in diameter, and about 6 feet 8 inches long; it was filled for about three-fourths of its capacity—50 to 60 cubic feet—with water; which is put in communication with one or more stationary boilers, from which steam is admitted through a perforated pipe into the water. The steam in the boilers had a pressure of 156 lbs. per square inch; the pressure obtained in the reservoir is 135 lbs. per square inch. If the communication were continued for a sufficient length of time, the pressure in the reservoir would become equal to that in the boiler; but the rate of absorption of heat and rise of pressure decreases gradually as the pressure is elevated, and for economy of time it is found expedient to arrest the process of heating-up at a lower limit of pressure and temperature than that in the boilers. The steam from the reservoir is admitted to an intermediate chamber, where it is maintained at a fixed pressure, the degree of which is adjusted by means of a throttle-valve. There is a pair of vertical cylinders, about 6 inches in diameter, with a stroke of about 12 inches, which work an intermediate crank-shaft, from which the four wheels are driven by outside coupling-rods. The wheels are about 26 inches in diameter, and the two axles are at a distance of 4½ feet apart. By a system of double frames, the passage over curves was facilitated. The locomotive was controlled by a brake having eight blocks, which were applied to the wheels successively. The stopping was thus effected promptly and without shock. The exhaust-steam was delivered into two air-surface condensers, one on each side of the car, each consisting of a group of small copper tubes. It was in contemplation to apply three cylinders to work as compound cylinders. The locomotive was heavy: it weighed, empty, 6·50 tons; full, 8·30 tons.

In trials of this engine on the tramway between Saint-Augustin and the Boulevard Bineau—a distance of 2½ miles—drawing one omnibus of 2 tons weight, with eight passengers—it was observed that the pressure in the reservoir fell from 156 lbs. per square inch to 50 lbs., during the double trip of 5 miles. For the first ten minutes of the service, no exhaust-steam was visible from the engine; but, afterwards, a considerable quantity of steam escaped, and proved an annoyance to the passengers who travelled in a following car drawn by horses.

In the more recently designed engines on M. Francq's system, constructed by M. Cail, the wheels were 2½ feet in diameter, and the axles were 4 feet 3 inches apart, that the engine might pass easily over curves of 15 metres, or 49 feet radius. The cylindrical reservoir was of steel plate, ·56 inch thick, and was 1 metre in diameter and 2 metres long, or 3·28 by 6·56 feet. The authorised limit of pressure was 213 lbs. per square inch, nearly fifteen atmospheres. The reservoir was coated with cork and wood. The regulator was so arranged that the driver might fix, before starting, the maximum pressure of the steam upon the pistons; and that, at the same time, he might reduce the pressure below the maximum, according to the requirements of the engine. The steam was exhausted into a cast-iron box, and thence into a condenser, disposed on the surface of the reservoir, before escaping into the atmosphere.

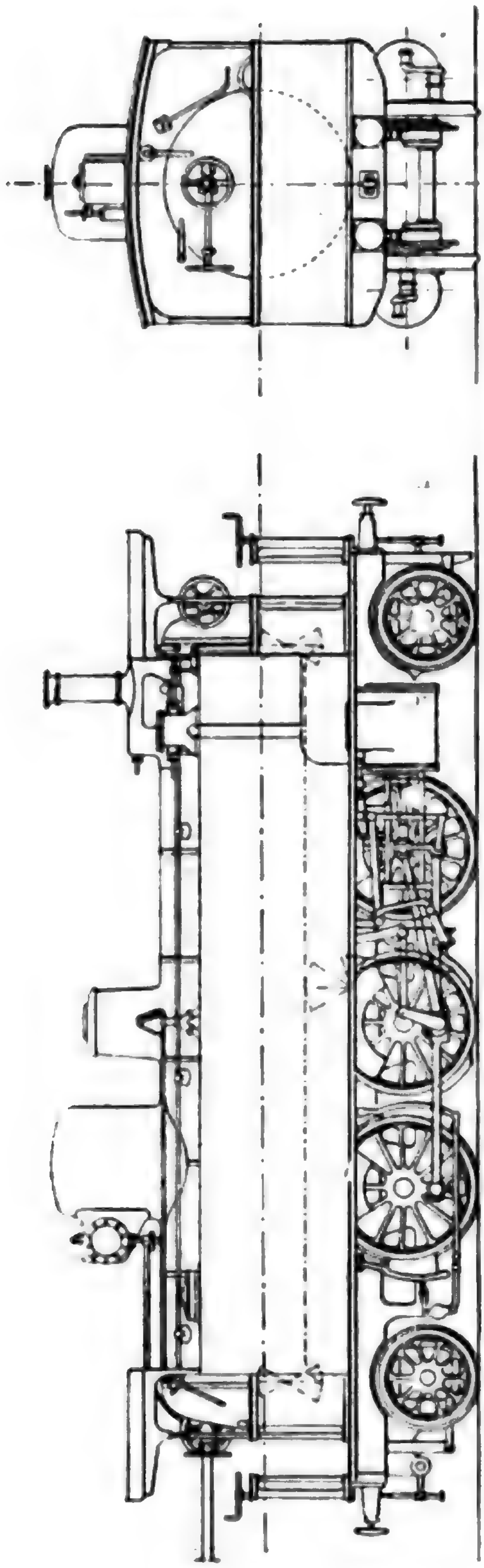
The advantages formally claimed for M. Francq's locomotive are: 1. The production of steam at a low cost, in a fixed boiler, using coal as it comes from the mine. 2. Reduction of dead weight, since no fuel is conveyed on the engine. 3. Employment of a high pressure for ascending inclines, and no escape of steam in descending inclines. 4. Reduction of the number of attendants, a single man being able to conduct the engine and keep a look out.

The cost for engine-power by this system on the Rueil-Marly Tramway, in France, 4·54 miles in length, is here given in detail, according to a statement by M. Gaune, the manager of the line, made in February, 1880 :—

COST FOR TRACTION PER MONTH (FRANCQ).

		Per Month. Francs.
Coal in stationary boiler for supplying hot water. 1,553 kilogrammes per day, per tonne . .	@ 29 fr.	1,357
Oil, 7·50 kilos. per day	,, 1·10 fr.	247·5
Tallow, 1·83 kilos. ,, ...	,, 1·10 fr.	60
Waste, 1·82 kilos. ,, ...	,, ·32 fr.	17·40
Brooms		
White and red lead, 43·20 kilos. per year . .	,, ·90 fr.	3
Fire-bars, 6½ per month		17
Spun yarn, 3·60 kilos. per year		0.3
Tiles		13
Packing, &c.		13
Tube-brushes		4
Foreman's wages, half for traction, 275 fr. ÷ 2 =		137·5
Firemen, 1 day and 1 night, per day . . .	,, 5·5 fr.	330
3 fitters, per hour	,, ·55 fr.	495
1 fitter for stationary boilers		165
1 smith and 1 stoker, @ 1—5th of their time .		59
3 drivers	2 @ 6 fr., 1 ,, 6·66 fr.	560
3 firemen on engines	,, 4 fr.	360
2 spare firemen		270
		4,116·7
The books from September 8, 1878, to February 9, 1880 (14 months), show an expenditure of 724·90 fr. for renewal of engines, or per month		60
Also 1,400 fr. per year for tyres, or per month .		117
Total for working and repair .		4,293·7

The total length run per month was 10,455 kilometres, or 6,534 miles; and this sum is at the rate of 6·57d. per mile run, of which 4·91d. is running expenses, and 1·60d. for repairs. Allowing a sinking fund for the repair and renewal of the stationary boilers, the total charge is estimated to amount to 7·28d. per mile run. The way is laid on one side of the highway, and consists of Vignoles rails on sleepers in ballast. It is not, therefore, a tram-



FIGS. 312 and 313.—Francq & Mesnard's Fireless Locomotive.

way as usually understood: the rails are plain, and the resistance of the way may be averaged, as a maximum, at 15 lbs. per ton-gross, or half the resistance of the grooved tramway; except on the Port Marly incline, 1¼ miles long, averaging 1 in 25 gradient, on which the rails are of an ordinary grooved section. The engines weigh 6½ tons empty, and 8·30 tons in working order. Taking 3, 4, or 5 cars with passengers, averaging 17 tons, the gross weight moved is, say, 25½ tons. The fuel is consumed at the rate of 15½ lbs. per mile run, or ·61 lbs. per ton-gross per mile, equivalent to twice as much, or 1·22 lbs. per ton-gross per mile on a grooved tramway.

The fireless locomotives, Figs. 312 and 313, more lately designed by Messrs. Francq & Mesnard for the service of the Metropolitan Railway of Paris, have a cylindrical reservoir, having segmental ends, about 5 feet 7 inches in diameter, 26¼ feet in length, with a capacity of about 620 cubic feet. Four-fifths of the capacity is occupied by water, which is heated by the aid of a powerful jet of steam supplied from stationary boilers. The water is heated up until equilibrium of pressure is established between the boiler and the reservoir. The temperature is raised to about 390° Fahr., corresponding to 15 atmospheres total pressure, or 225 lbs. per square inch. The steam from the reservoir is passed through a reducing valve by which the steam is reduced to the required working pressure. It is then passed through a tubular super-heater situated within the receiver at the upper part, and thence through the ordinary regulator to the cylinders. The exhaust-steam is expanded to a low pressure in order to obviate noise of escape. In certain cases the exhaust steam is condensed in closed vessels, which are only in part filled with water. In the upper free space a pipe is placed into which the steam is exhausted. Within this pipe another pipe is fixed, perforated, from which cold water is projected into the surrounding steam, so as to effect the condensation as completely as may be. The heated water falls on an inclined plane, and flows off without mixing with the cold water. The condensing water is circulated by means of a centrifugal pump, driven by a small three-cylinder engine.

In working off the steam from a pressure of 15 atmospheres to 4½ atmospheres, 530 cubic feet of water at 390° Fahr. is sufficient for the traction of the trains, for working the circulating pump for the condensers, for the breaks, and for electric lighting of the train. At the stations the locomotive takes from 2,200 to 3,300 pounds of steam, nearly the same as the weight of steam consumed during the run between two consecutive charging stations. There is 210 cubic feet of condensing water. Taking the initial temperature at 60° Fahr., the temperature rises to about 180° Fahr. after the longest runs underground.

The locomotive has ten wheels, on a base 24 feet long; of which six are coupled, 4½ feet in diameter. The extreme wheels are on radial axles. The cylinders are 23½ inches in diameter, with a stroke of 23½ inches.

The engine weighs, in working order, 53 tons, of which 36 tons are on the coupled wheels. The speed varies from 15 miles to 25 miles per hour. The trains weigh about 140 tons.

CHAPTER V.

COMPRESSED-AIR LOCOMOTIVES AND CARS.

COMPRESSED-AIR engines necessarily derive their power at second-hand; and they therefore work at a disadvantage, in point of efficiency, compared with steam-locomotives, in which the force is generated and expended simultaneously. A supply of air, previously compressed, is taken in by the propelling engine, and it is gradually dispensed to the working cylinders, where it works by expansion, and from which the force is transmitted to the driving-wheels by mechanism similar to that of a steam-locomotive. If the reverse actions—of compressing the air, and working it by expansion—could be made to take place between the same temperatures, pressures, and volumes, the work by expansion would be an exact duplicate, in reverse, of the work expended for compression; and the efficiency of the combined compressor and motor would be equal to 100 per cent., irrespective of losses by friction and clearance. But, under practical conditions, the initial temperature for expansion is not more than that of the surrounding atmosphere; and in working, by expansion, back to atmospheric pressure, even between the same extremes of pressure, the volumes are smaller, since the temperatures are lower. The efficiency must, therefore, be less than 100 per cent.

When air is compressed mechanically, the temperature is raised; and, if none of the heat so generated be permitted to escape, the air would be "adiabatically" compressed. If air be subjected to compression, so that the pressure be doubled, trebled, &c., or so that, taking the initial pressure, at 62°, as 1—

the relative pressures are as 2, 3, 4, 5, 10;
the final temperatures are 178°, 258°, 321°, 373°, 559°.

It may be noted here that, taking the initial temperature, 62°, as 1, the final temperatures are, very roughly, as 3, 4, 5, 6, 9.

In practice, as was said, the air cannot be employed at these high temperatures. It is, in fact, cooled down by radiation and conduction, to the temperature of the surrounding atmosphere, before it is applied to do work. The loss of efficiency by the intermediate fall of the temperature of the compressed air from the absolute temperature T'', due to the compression, to the absolute atmospheric temperature T, is simply the proportion which this fall $(T'' - T)$, bears to the higher temperature T''. It is so, because the volume is as the absolute temperature T'', and the loss of temperature $(T'' - T)$, indicates the loss of volume by contraction, under the same pressure. For instance, in compressing dry air at 62° to two atmospheres of pressure, in a non-conducting vessel, the temperature is raised to 178°, and the fall, in reverting to 62°, is (178 — 62 =) 116°. The loss of efficiency due to this decline of temperature, is the proportion of 116° to (461° + 178° =) 639°, the maximum absolute temperature,* thus:—

(461 + 178 =) 639°
(461 + 62 =) 523°

Difference, or loss, 116° = 18 per cent. of the maximum absolute temperature.
Leaving 523° = 82 do. do. do.

The reduced efficiency here is 82 per cent. Take other examples:—

For ratios of pressure, or atmospheres,

2, 3, 4, 5, 10,

---

* Absolute temperature is an expression signifying the measure of total heat in a body, as from the bottom of the scale of temperature. The zero of the scale of absolute temperature, or the point of no-heat, is 461 degrees below the zero point of the Fahrenheit scale; and to find the absolute temperature for any temperature indicated by the thermometer, 461° are added to the indicated temperature. For instance, the absolute temperature for 62° F. is (461 + 62 =) 523°.

the final temperatures for compression are

178°, 258°, 321°, 373°, 559° F.;

and the losses of temperature, by the fall of the temperature to 62°, the initial temperature for expansion, are

116°, 196°, 259°, 311°, 497°;

whilst the reduced efficiency is

82, 73, 67, 63, 51 per cent.;

and the loss of efficiency is

18, 27, 33, 37, 49 per cent.

Thus, it is obvious that the lower the degree of compression applied to the air, the less is the rise of temperature, the less is the loss of heat by dissipation, and the greater is the efficiency of the machine.

As air under adiabatic compression may rise to temperatures which are impracticable, so air under adiabatic expansion—that is, expanded behind a piston, in a non-conducting cylinder—may fall to temperatures which are impracticable.

Thus, when the initial temperature is 62°, for ratios of adiabatic expansion,

2, 3, 4, 5, 10,

the final temperatures are,

— 33°, — 81°, — 111°, — 133°, — 193°.

It is clearly as impracticable to work a compressed-air engine in such low temperatures, when every particle of moisture and lubricant would be frozen, as amongst the high temperatures previously noticed. Expedients are, therefore, employed for keeping the rise of temperature, during the compression of air, within feasible limits; and for limiting likewise the fall of temperature, during the expansion of compressed air. The former is effectively done by surrounding the compressing pumps with cold water, and by injecting cold water, in finely divided spray, into the mass of air whilst undergoing compression. Dr. Colladon has probably done more for the improvement and perfecting of air-compressing machinery than any other operator. In the air-compressing machinery at the works of the St. Gothard Tunnel, at Airolo, arranged by Dr. Colladon, it has been found by experiment that, by the means above indicated, the rise of temperature of air, even when the air is condensed under a pressure of ten atmospheres, was limited to from 36° to 54° F. The pistons had a stroke of 17·3 inches, and they made from 120 to 180 strokes per minute, giving speeds of piston of over 260 feet per minute. A quantity of cold water, equal in volume to 1-1,000th of the volume of the stroke, was injected during each stroke.

The clearance space at each end of an air-compressing cylinder affects very sensibly the yield, or *rendement*, of compressed air, by reducing it, to some extent, below the total volume of the stroke, or the space described by the piston for one stroke. This effect—the reduction of yield—is obviously due to the fact that the compressed air left in the clearance-space, after the stroke of the piston is completed, expands upon the piston as it recedes, and so far monopolises the cylinder, to the exclusion of a fresh supply of air, until its pressure falls, in due course, to an equality with that of the atmosphere. The reduction of yield, by this cause, increases as the pressure of compression is increased. In a series of observations made at Airolo, with the pumps already mentioned, having a stroke of 17·3 inches, with a clearance-space 1-80th of the volume of the stroke, making 64 turns per minute, the yield in weight of air was only 78 per cent., in compressing air in the reservoir by the pump, from 6 atmospheres to 7 atmospheres. At higher pressures the yield became still less, as follows:—

Compression.	Yield, in weight of air.
From 6 to 7 atmospheres	78 per cent.
,, 7 to 8 ,, ...	74 ,,
,, 8 to 9 ,, ...	66 ,,
,, 9 to 10 ,, ...	59 ,,

In performing work with compressed air, on the contrary, accompanied by expansion, the fall of temperature is to be checked, that it may be prevented from falling to or below the freezing point. There is a well-known practical difficulty in working compressed air expansively. The extreme fall of temperature causes the freezing of moisture and the hardening of lubricants about the mechanism. For this reason, the working of air expansively is confined to narrow limits; and the air is admitted to the cylinder for nearly the whole of the stroke, that the cooling which results from expansion upon a piston may be reduced to a minimum. The most efficacious means of checking the fall of temperature, and mitigating the inconveniences of it, is to saturate the compressed air with moisture or vapour. According to the investigations of M. Mallard, the following are the ratios of expansion to which dry air, and air saturated with vapour or moisture, respectively, may be worked before they fall to the temperature 32° F.:—

EXPANSION OF AIR DRY AND MOIST.

Temperatures.		Ratio of expansion.	
Final.	Initial.	Dry air.	Air with sufficient moisture or vapour.
Fahr.	Fahr.	Ratio.	Ratio.
32°	40°	1·05	1·10
32°	50°	1·13	1·24
32°	60°	1·22	1·38
32°	62°	1·23	1·41
32°	68°	1·28	1·50
32°	70°	1·30	1·56
32°	80°	1·37	1·75
32°	96°	1·47	2·00
32°	100°	1·57	2·28
32°	110°	1·67	2·63
32°	120°	1·76	3·00
32°	130°	1·88	3·45
32°	140°	2·00	4·00

As the steam is condensed during expansion, the heat that is liberated is absorbed by the air.

It was seen that when the compression of air was carried to 10 atmospheres, the efficiency for working in a compressed-air engine was only 51 per cent. Add, that the efficiencies of the machines themselves—the compressor and the power engine—are factors for the calculation of their resultant efficiency, and if the efficiency of each machine be taken at 80 per cent., the combined percentage of the two machines is $\left(\frac{80 \times 80}{100} =\right)$ 64 per cent., or about two-thirds; and 64 per cent. of 51 per cent. is 33 per cent., the resultant efficiency of the combined compressor and engine, working to 10 atmospheres. Similarly, it is found that the resultant efficiency, working to 2 atmospheres, is 52 per cent. The less the degree of compression, the greater is the efficiency, because the less is the proportional loss from the intermediate reduction of temperature. In general practice, the resultant efficiency rarely exceeds 30 per cent. But, to give a character of precision to the relations of the first power and the final performance, the following are the resultant efficiencies, deduced from actual experiment, of 16-inch cylinder air-compressing engines, and 10-inch cylinder compressed-air engines, cutting off at 3-4ths, constructed by Messrs. John Fowler & Co. for Sir George Elliot—at work at Powell Duffryn Collieries. The air-compressing cylinders were immersed each in a cold-water bath, open at the upper side. The resultant efficiency is here expressed by the ratio of the brake-power of the compressed-air engine to the indicator-power in the steam-cylinder of the air-compressing engine *:—

Effective pressure of air in receiver:—40·0, 34·0, 28·5, 24, 19 lbs. per square inch.

Indicator horse-power in the steam-cylinder:—59·4, 46·2, 35·8, 25·8, 11·8 I.H.P.

Resultant efficiency:—25·8, 27·1, 28·5, 34·9, 45·8 per cent.

MÉKARSKI.

Early in 1876, a tramway car, propelled by compressed air, was constructed by M. Mékarski, and tried on the Courbevoie line of

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* The substance of this chapter on the principles and the action of compressed-air motors is derived from the author's *Manual of Rules, Tables, and Data* (1877), pages 898—914.

the Tramway Nord, in Paris. The car is, in general outline, on the model of the cars of the Compagnie des Tramways. The body is 11½ feet long, and accommodates twenty passengers inside; there is also room for fourteen passengers outside, on a spacious platform at the rear. Compressed air, of 25 atmospheres, is stored in eight cylindrical reservoirs of plate-iron, from 12 to 16 inches in diameter, placed transversely underneath the carriage, and connected together. They are in two separate series. The capacity of the principal series is 52 cubic feet, and that of the second, or reserve series, is 17 cubic feet. An upright reservoir, 14 inches in diameter and about 5 feet in height, is placed at the fore end of the car, is three-fourths filled with water heated to 340° F., corresponding to a pressure of 103 lbs. per square inch above the atmosphere. The compressed air, as drawn off for consumption, is passed through this reservoir, in which it becomes saturated with vapour. The mixture of air and water occupies the upper part of the reservoir. The frame of the car is of wrought iron, 5 feet 10 inches wide, and 18 feet 8 inches long. The car runs on two pairs of wheels about 28 inches in diameter, and placed 6 feet 10 inches apart. One pair of the wheels is driven by a pair of cylinders, 5 or 6 inches in diameter, with about 10 inches of stroke. The weight of the car is 4¾ tons, and with a load of 30 passengers the weight is 7 tons.

The air is wire-drawn to a pressure of 5 atmospheres for working in the cylinders. M. Mékarski calculates that the fall of pressure by wire-drawing, from 25 atmospheres to 5 atmospheres, followed by the complete expansion on a piston from 5 atmospheres down to atmospheric pressure, results in an efficiency of 62 per cent.—that is to say, a loss of 38 per cent.; and that this loss is compensated by the re-heating of the air during expansion by the intermixed steam. The expenditure in thus re-heating the air is only a small proportion of the total fuel consumed. The quantity of heated water supplied to the reservoir of the car is about 3 cubic feet, at a temperature of 340° F., and the car returns with about 2¾ cubic feet of water at 212° F., the difference representing the consumption of about 2 lbs. of coal, whilst the fuel consumed in charging the reservoirs with compressed air amounts to 33 lbs. of coal. The cooling of the heated water, and the diminution of pressure of the air in the reservoir, take place simultaneously in the course of the journey; and thus the elements of the mixture may be maintained in sensibly constant proportions. It is stated that the quantity of air consumed does not exceed 11 cubic feet per mile-run.

The Mékarski car works well as a mechanical engine—free from smoke, steam, noise, and fumes.

Mékarski's system of propulsion by compressed air was adopted for working the Nantes tramways, which consist of a line of tramway 3¾ miles in length, 4 feet 8½ inches in gauge. The line is generally level. The cars carry 19 passengers inside, and 12 on the platform at the rear. The compressed-air reservoirs are placed between the frame-plates, beneath the body of the car. They are charged with a pressure of 30 atmospheres, or 450 lbs. per square inch. The pressure is reduced to from 4 to 6 atmospheres, or 60 lbs. to 90 lbs. per square inch, for admission to the cylinders. There are two stations for compressing the air-supply, at one of which, the larger, there are four 50 horse-power engines, of which two are at work daily. Each engine drives two pumps, by which the air is compressed successively to 6 atmospheres and 30 atmospheres, stored in reservoirs. From these, the cars are charged in twenty minutes, the charge being sufficient for one trip. The trip of 3¾ miles is run in forty minutes, making an average speed of 5½ miles per hour. The total time per trip is one hour. The total cost for wages and material for repair of the working plant, was, for the first year of the tramway, 1·37d. per mile run. Of course, the expenses for repair are greater as the plant becomes worn out; and the expenses may, it has been estimated, by-and-by amount to 7½d. or 8d. per mile run.

The weight of the car, in working order, is 6 tons; and, allowing 3 tons for passengers and attendants, the gross amount moved is 9 tons. The cylinders, two in number, are 5⅜ inches in diameter, with a stroke of 10¼ inches. According to Sir Frederic Bramwell, who reported on the system at Nantes, 4½ tons of coal are consumed by the compressing engines per day, in winter, when 86 double trips are made per day, or (86 × 2 × 3¾ =) 645 miles run; with a consumption of 15·64 lbs. of coal per mile-run, or 1·74 lb. per ton-gross moved per mile-run.

Two Mékarski locomotives were placed on the Wantage Tramway in July, 1880, and worked the traffic for three months. The engines made, on ordinary days, four double-trips, with one passenger-car; and, on special days, five double-trips, frequently taking two loaded cars in both directions. The initial pressure was 30 atmospheres, and each engine made the double-trip, 5 miles, with one charge of compressed air, the pressure falling to about 5 atmospheres in the battery of three working reservoirs, and to 27 atmospheres in the fourth, or reserve reservoir. The pressure at which the air was supplied to the cylinders seldom exceeded 70 lbs. per square inch. The speed of travelling on the line averaged 9 miles per hour; the mileage run by two cars amounted to, say, 40 miles per day, or, allowing for special trips, an average of 42 miles per day. Mr. G. Stevenson, engineer of the line, estimated that 24 cwt. of coal was consumed per day on the compressing power—an absurdly excessive consumption, showing, evidently, that the means were not properly proportioned to the end.

Scott-Moncrieff.

Mr. Scott-Moncrieff's car, worked by compressed air, resembles in appearance an ordinary tramway-car. The reservoirs and machinery are carried on a frame below the floor of the car. In the central portion the engines are carried. In the car first made, and started for trial, about the middle of 1875, on the Vale of Clyde Tramway, there were six reservoirs holding compressed air—three at each end of the car. The air was supplied to the reservoirs at a pressure of 350 lbs. per square inch. There were two air-cylinders, 6 inches in diameter, with a stroke of 14 inches. The supply of air was wire-drawn before it was admitted into the cylinders, and cut off so that it expanded to, and was exhausted at atmospheric pressure. The total weight of the car was 6¾ tons; with 40 passengers, 10½ tons. Mr. Scott-Moncrieff states, that during a trial of the car, lasting fourteen days, on the line between Govan and Paisley Toll, the reservoirs were charged, after every three-miles run, with compressed air having a pressure of 310 lbs. per square inch, which was worked until the pressure fell to 100 lbs. or 110 lbs. The average pressure in the cylinders was about 22½ lbs. per square inch. Mr. Scott-Moncrieff states that his car consumed from 400 to 500 cubic feet of air as at atmospheric pressure per mile, and he is of opinion that a compressing-engine of about 150 indicator horse-power would be capable of keeping up a service of 1,000 miles per day.

Mr. Scott-Moncrieff's engine resumed regular duty on the Vale of Clyde for a few weeks in the beginning of 1877. From the results of his experiments, he concluded that the cost price of working—including drivers' wages, lighting, cleaning—was between 3d. and 4d. per mile-run.

BEAUMONT.

A compressed-air car on Major Beaumont's system was constructed by Messrs. Greenwood & Batley. The initial pressure in the reservoirs, which have a capacity of 65 cubic feet, was 1,000 lbs. per square inch. This high pressure was adopted, for it was found that the higher the pressure the greater was the efficiency. This conclusion is apparently in contradiction to the conclusions drawn from other experience, as well as from the elementary data which have already been considered. But the explanation lies in the use of a compound-engine of four cylinders, in which the air is successively expanded down from an initial pressure of 1,000 lbs. per square inch, to the pressure at which the air is exhausted into the atmosphere. The volumes of the cylinders successively are as 1, 3, 9, 27, having a common ratio of 1 to 3, and showing that the air may be expanded in the engine as many as 27 times. When the pressure falls off, the first cylinder is closed to the air, which is then turned on direct to the second cylinder; again, on further need, it is closed to the second cylinder, and turned on direct to the third, and ultimately direct to the fourth. As Mr. Greenwood remarks, the same power may thus be got out of the engine under a decreasing pressure. He calculated on a loss of four-fifths of the steam-power used for compression; but he hopes to reduce the loss to two-thirds, leaving one-third of the work of the steam as the useful work done. The horse-power given out per cubic foot of air at 1,000 lbs. pressure is under 5 horse-power. The engine above noticed has run 6½ miles with a load of 4 or 5 tons; but Mr. Greenwood considers that with a reservoir of 100 cubic feet of capacity, fully charged, a run of ten miles could be made. The weight of such an engine would be from 4 to 4½ tons.

The four compounded cylinders have been replaced by two sets of compound cylinders, two to each set, in each of which sets the air is expanded from the first cylinder into the second. The temperature of the expanding air is maintained to a greater or less degree by the external application of heat in a steam-jacket. An engine of this construction was, in 1881, at work on trial on the Leytonstone extension of the North Metropolitan Tramway.

HUGHES AND LANCASTER.

From the results of trials made by the author with one of Messrs. Hughes & Lancaster's low-pressure compressed-air tram-cars, propelled by means of four single-acting 5-inch cylinders, of 3 inches stroke, it appears that the consumption of compressed air was at the rate of 30½ pounds per mile-run for a level. The car, with passengers, weighed 4¼ tons; and the work done was at the rate of 22,070 foot-pounds per pound of air. The maximum working pressure of compressed air was 132 pounds per square inch.

CHAPTER VI.

CABLE TRACTION.

THE working of tramways by cable haulage is effected by the employment of an endless wire rope continuously moving in one direction, supported on pulleys within a slotted tube laid below the surface of the street or roadway, or between the rails of a surface or an elevated railway. The rope is driven by means of a fixed or stationary steam-engine or other motor, situated at a suitable place near the line, the motion of the cable being intermittently communicated to the cars, for starting and stopping, by means of a gripper attached to the car.

The principle of cable traction has been successfully applied on railways and in mines for many years. The first practical test for cable traction was made in San Francisco, in 1873, by Andrew S. Halliday and his associates, A. E. Hovay, W. Eppelscheimer, and Henry Root. For heavy street traffic the cable is extensively employed.

The slotted tube is of concrete. It is virtually an arch of which the key is left out. It is constructed with yokes or frames of angle-iron or cast-iron. The latter material is preferred. The sides act as cantilevers to resist the lateral pressure of the soil, packed by heavy waggon traffic, and, in cold climates, the pressure in addition due to the expansion of the soil by freezing. The first tube was 12 inches wide, 15 inches deep, or 22 inches below the level of the street. The slot is usually ¾ inch wide, and it is formed by two slot rails which are fastened to the yokes at the upper side. The slot rails, of overhung formation, are brought up to the surface level and require to have great vertical and lateral strength, whereby they are nearly as heavy as the way-rails.

The gripper is a powerful vice within the tube, supported by or suspended from the car by means of a thin shank through the slot. It is worked from the platform by a lever or a hand-wheel through the medium of an excentric toggle-joint or an equivalent device, and is caused to grip the rope with a pressure sufficient to impart the motion of the rope to the car. The rope is grasped between two flat plates or jaws, upper and lower, usually of steel, and from 18 inches to 20 inches long, lined with removable dies for wear, slightly grooved to fit the rope. Grips are of two types—vice-grips and roller-grips. The former comprise the side grip, the top grip, the bottom grip. Side grips are usually constructed with a pair of jaws at each side of the shank. They take the rope on either side without turning the cars.

The cable is a steel wire-rope, commonly of 6 strands twisted round a heart of hemp rope, each strand of 19 wires, of which 7 wires form the heart of the strand, round which the other 12 wires are wrapped. Sometimes the 12 enveloping wires are larger than the 7 heart wires to provide allowance for wear. Ropes are also made with 6 strands of 16 wires each, or 7 strands of 19 wires, usually laid 12 over 6 over 1. On straight lines 19 wires do good service. Ropes are also made with a wire centre. Though stronger than others they are not so flexible.

Cables are from 1 inch to 1½ inches in diameter. The usual sizes are 1⅛ inches and 1¼ inches. The 1¼-inch ropes weigh 2½ lbs. per foot, and their breaking weight is about 80 tons. The average life of common ropes is 12½ months, or 88,402 miles, making about 85,000 miles per year. The general average life for all lines and ropes is about 8 months, or from 40,000 to 150,000 miles. According to the system of wire rope known as the Lang lay the wires forming the strands, and those of the strands themselves, are laid in the same direction instead of in opposite directions. Thus, a larger portion of each outside wire is exposed for wear, the rope is of greater flexibility, and a maximum degree of wear is attained without fracturing of the wires.

The driving machinery operates on the rope by frictional contact with two large V-grooved pulleys in tandem, usually lined with wood or with babbit metal. The rope makes two wraps over the pulleys, like the letter S, known as the front driver and the back driver. The pulley shafts are geared together by two spur-wheels, one of which is driven by a toothed wheel on the engine shaft. Frictional contact is maintained by tension apparatus, in which a large sheave is mounted on a car which travels to and fro on a track laid over a long, narrow pit. A tail rope or a chain is connected to the car, and is led over a pulley, suspended within a deep well, and loaded with a heavy weight, which, taking up the slack, maintains tension on the cable. The length of the track is from 150 feet to 200 feet for long lines. The length of the tail rope is adjustable by means of hand-wheel and worm-gear on the car.

The steam-power is from 200 to 1,500 horse-power in duplicate, averaging 25 actual horse-power per car, including reserve. In Melbourne, Australia, the aggregate length of cable is 91 miles. There is 15 horse-power per car of the average number of cars running. On American lines there is an average of 4·6 horse-power to move 1,000 feet of cable. The power required to move the cable alone is from 35 per cent. to 75 per cent. The average of twelve roads is 54 per cent. The approximate "steam horse-power" to work a line employing less than 10 miles of rope may be estimated as follows:—Allow 4 horse-power to each 1,000 feet of rope, reckoning each right-angle curve equivalent to 1,500 feet of straight way. Add 3 horse-power for each car of ordinary size, and 60 horse-power for engines and machinery.

Cable Tramways in San Francisco and Chicago.

Several tramways are in operation in San Francisco. Of these, the Clay Street Tramway has a double way, about 5,500 feet, or 1·04 miles in length, of 3½ feet gauge. It rises to a height of 307 feet above the starting-point, in the course of 2,475 feet, making an average gradient of 1 in 8, the steepest gradient being 1 in 6.

On the other tramways of San Francisco there are gradients of 1 in 5, on which cars are drawn upwards and downwards with ease and security. A car with its coupled dummy in front, when fully loaded, hold together 44 passengers.

The disposition of the dummy car, tube, and gripping apparatus is shown in Figs. 314 and 315. Below the surface, and about the middle of each way, there is a channel, or technically a tube, within which the endless rope travels on pulleys. The tube also affords protection for the gripper A, connected to the dummy on the way by means of a flat bar of iron which passes up through the longitudinal slot in the upper part of the tube. The throwing of the gripper into action, by grasping the rope, induces the necessary motion of the car, which, of course, travels at the same velocity as the rope. The slot is not immediately over the centre of the tube, but on one side, in order that grit or other droppings falling through the slot does not lodge on the rope, but falls to the bottom of the tube. By this means, also, the gripper passes by and under the upper pulleys, C, Fig. 315, and over the lower pulleys, D, Fig. 314 in the tube.

The rope, endless, travels down one way and up the other. At the summit the rope is turned on to one series of 8-feet pulleys, and led into the engine-house. Thence it passes out by another series of 8-feet driving pulleys, the rope making a right-angle turn to the left and right after leaving the house. At each terminus of the road the rope passes half round an 8-feet horizontal sheave, fixed to a tension-carriage moveable horizontally, for the purpose of maintaining uniform tension on the cable. The pulleys D, Fig. 314, by which the rope is supported in the tube, are from 11 inches to 12 inches in diameter, secured to cast-iron standards placed 30 feet apart, with man-holes and doors for access. The sheaves on the Chicago road are formed in halves bolted together, with wood between, the dividing plane being at right-angles to the axle of the pulley. The wood thus forms the bottom of the groove, and is exposed to the wear. It is renewed every two months. The slot-rails are supported by intermediate cast-iron standards, placed at from 3 feet to 4 feet apart, and they are fixed at a distance of ¾ inch apart, transversely, forming the slot. Sheet-iron tubing, E, Fig. 314, about 10 inches wide, reaching upwards to within 15 inches of the surface of the street, is bolted to the cast-iron standards. The tubing is packed outside with earth, and, to prevent the earth from getting into the tubing, a 3-inch plank, F, Fig. 314, is placed on edge on the standards, the upper edge being at the level of the underside of the slot-rail. The running rails are laid on longitudinal wood sleepers, about 3¾ inches wide, 5½ inches deep, and these are let into and supported by short cross sleepers, the inner ends of which have a bearing on the standards, and are bolted to them.

According to another system of construction in San Francisco the standards are formed from ordinary railway-bars, bent as required, braced and arranged to carry both the slot-rails and the running rails. A culvert, or "tube," of Portland-cement concrete is constructed in place of sheet-iron tubing.

Where a steep rise occurs in the road, the wire rope is kept down by small pulleys, as shown in Fig. 315, from 6 inches to 8 inches in diameter, mounted in a frame. Where the rope leaves a summit and descends, it is passed over a pulley of about 4 feet in diameter.

The cable is about 11,000 feet in length, 1 inch in diameter, of crucible steel wire, of 6 strands of 19 wires. Each wire has a tensile strength of 160,000 pounds, or 71 tons, per square inch. It can be bent in any direction without fracture. The wire rope is found to stretch 1 per cent. of its length before being too much weakened for use. The average life of the rope is about fifteen months. On some tramways the length of rope is 17,000 feet. A tensional-pulley system is provided in the engine-house, about 50 feet in length.

The shank B of the gripper A, Fig. 314, is, as before noted, a flat bar of iron 5½ inches wide, ⅝ inch thick, which works through the longitudinal slot, and to the lower end of which the gripper attachment is made. This consists of two pairs of 3½-inch pulleys, placed obliquely, the pulleys of each pair being 10 inches apart and secured to sliding frames, mounted with jaws for the purpose of taking a firm hold of the rope. The small sheaves act as guides

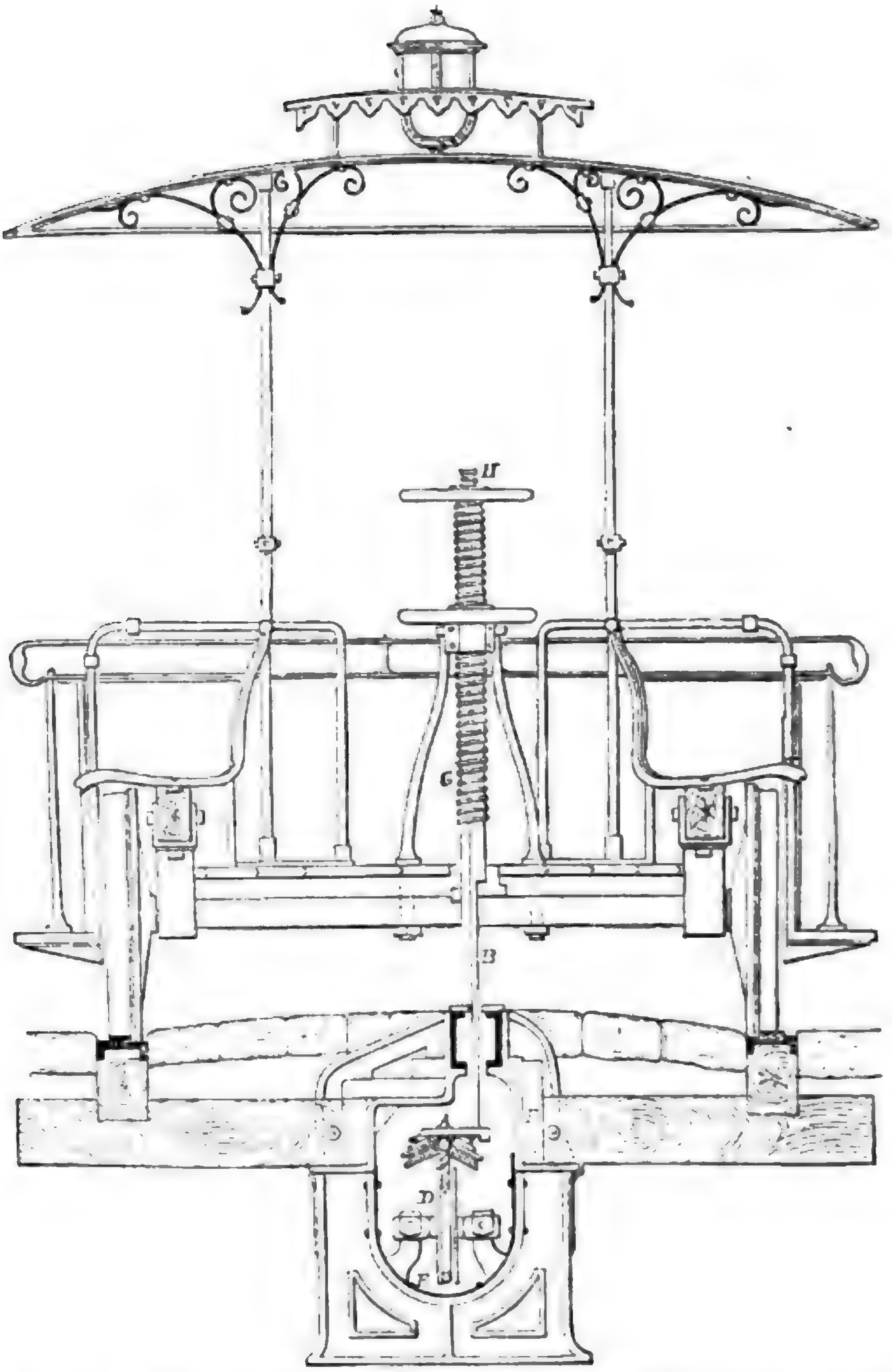

FIG. 314. Cable Tramways, San Francisco: Transverse Section of Way, Tube, and Gripper.

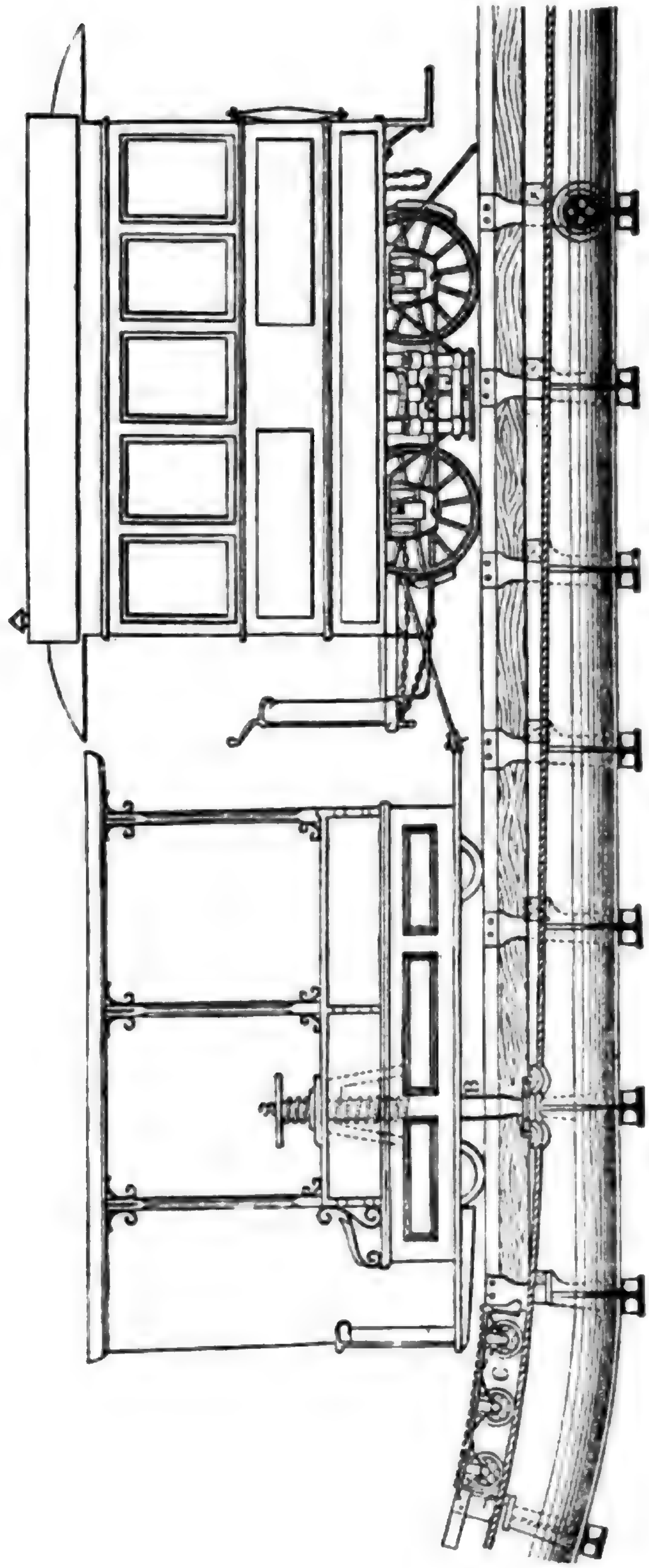

FIG. 315. Cable Tramways, San Francisco: Elevation, showing disposition of Tube, Dummy Car, and Gripper.

for the rope to pass between the jaws, and they are gradually tightened on the rope by the screw G. The dummy, through the medium of the shank and pulleys, gradually acquires the velocity of the rope until the gripping jaws are brought into action, and firmly acquires a hold of it by means of the screw G.

The speed of the cable is 6 miles per hour, running for 16 hours a day. It is driven by two horizontal steam-engines, each of 100-horse power, of which one is kept in reserve; and about 2,900 pounds of small coal is consumed per day. The total cost of the engines and machinery was about £3,000. A double way of the tramway, having a tube 30 inches deep, costs, on an average, £10,000 per mile, not including rolling stock. For a tube 12 inches deep the cost would probably be £8,000. It is believed that a gauge of 3½ feet is as effective as the 5-feet gauge, and is frequently more convenient. The dummy carries 18 passengers, the car 26; together, 44. Each vehicle is provided with a powerful break.

Many of the cable roads have right-angle curves, for which the rope is deflected by means of two horizontal 8-feet pulleys, with other auxiliary pulleys.

HIGHGATE-HILL CABLE TRAMWAY, LONDON.

The Highgate-hill cable tramway was the first cable line constructed in this country. The works were carried out by the Patent Cable Tramways Corporation, under the supervision of Messrs. Eppelsheimer and Colam; and the line was opened in May, 1884. It is nearly ¾ mile in length, of double way, constructed to a gauge of 3½ feet, between the Archway Tavern, Upper Holloway, and Southwood Lane, near the summit of Highgate-hill.

The gradients vary from 1 in 11 to 1 in 15, and the curves from 250 feet to 3,000 feet in radius. The way was laid with steel rails of the Dugdale type, weighing 52 pounds per yard. The cable consists of crucible steel wire, in strands closed round a hemp core. It is 3 inches in circumference, or 15/16 inch thick, and it weighs about 5 tons complete. It passes round two 8-feet pulleys at the termini, in brick pits. The endless rope is carried on pulleys beneath the track, in a "tube" of concrete, 10½ inches deep, 8½ inches wide. It is driven by two independent horizontal steam engines, each of 25 nominal horse-power, affording service in duplicate. The speed of the rope is from 5 miles to 6 miles per hour.*

EDINBURGH NORTHERN CABLE TRAMWAYS.

Mr. W. N. Colam, the engineer of the Edinburgh Northern Cable Tramways, describes the two routes of which the tramways are composed—the Trinity route and the Stockbridge route.†

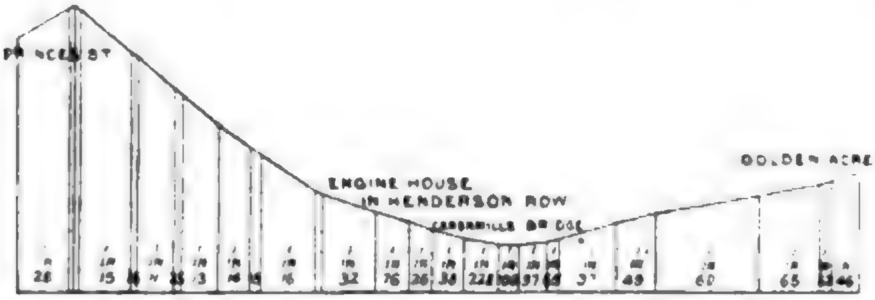

FIG. 316. Edinburgh Northern Cable Tramways: Gradient Diagram, Trinity route.

The gauge of the ways is 4 feet 8½ inches. The two lines start from Princes Street, one in Hanover Street, the other in Frederick Street. The first named, or Trinity route, passes Henderson Row, where the cables branch off to the engine-house. It takes 18 curves, varying in radius from 80 feet to 980 feet, the smallest curve being less than a right angle. It is also diverted at various places by nine large pulleys. The total height ascended is 187 feet. The double way is 1½ miles long. It is almost entirely on gradients, varying from 1 in 11 to, for the greater part, 1 in 60 approximately. Fig. 316 is a gradient diagram of the line.

The gradient diagram, Fig. 317, is that of the Stockbridge route, on which the steepest gradient is 1 in 13. The length of way, double line, is 1·20 mile. After passing over 100 feet curves into the Royal Circus, the line is almost entirely a series of curves, passing through steep and very narrow roads. At Stockbridge, where the cable leaves for and returns from the engine-house, the line, though curvy, is nearly level. The cable traverses 28 curves of radii varying from 80 feet to 400 feet. It is diverted by means of nine large pulleys. The line rises 173 feet. The tramways were opened in January, 1888.

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* Since the above paragraphs were written, the line has stopped working.

† In a paper read before the Association of Municipal and Sanitary Engineers of Great Britain.

The road is shown in section by Figs. 318 and 319, having two lines of way. The conduit or "tube" is of concrete; it is 19 inches deep from the surface and 9½ inches wide. Cast-iron tube-frames are embedded in the concrete, at 3½ feet apart between centres, to which the slot-rails are bolted, forming a slot ⅝ inch wide. The frames are 1 inch thick in the webs, and they weigh 135 lbs. each. They are lined up in place before the concrete is poured in. Thus a solid mass is constructed, by which subsidence or closing, of the slot, is prevented. The extreme depth occupied by the tube is 26 inches below the surface. The bottom of the tube is 7 inches thick, the sides 6 inches, and the concrete floor of the way, 5 inches. A 6-inch clay pipe is laid under the bottom of the tube, by which it is drained from recesses in the concrete in which the supporting pulleys are mounted at 50 feet apart between centres. On two of the worst curves, there are convenient subways between the two lines of way, from which pulleys may be renewed or adjusted.

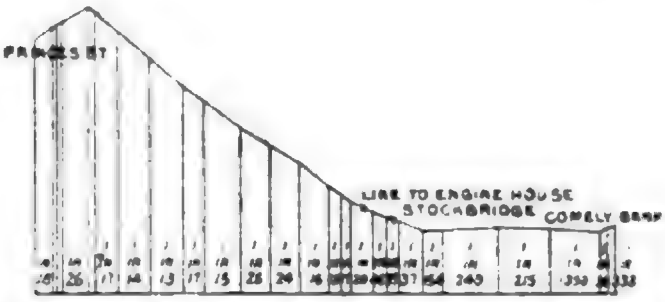


FIG. 317.—Edinburgh Northern Cable Tramways: Gradient Diagram, Stockbridge route.

The running rails are of girder type, 6 inches deep, of steel,

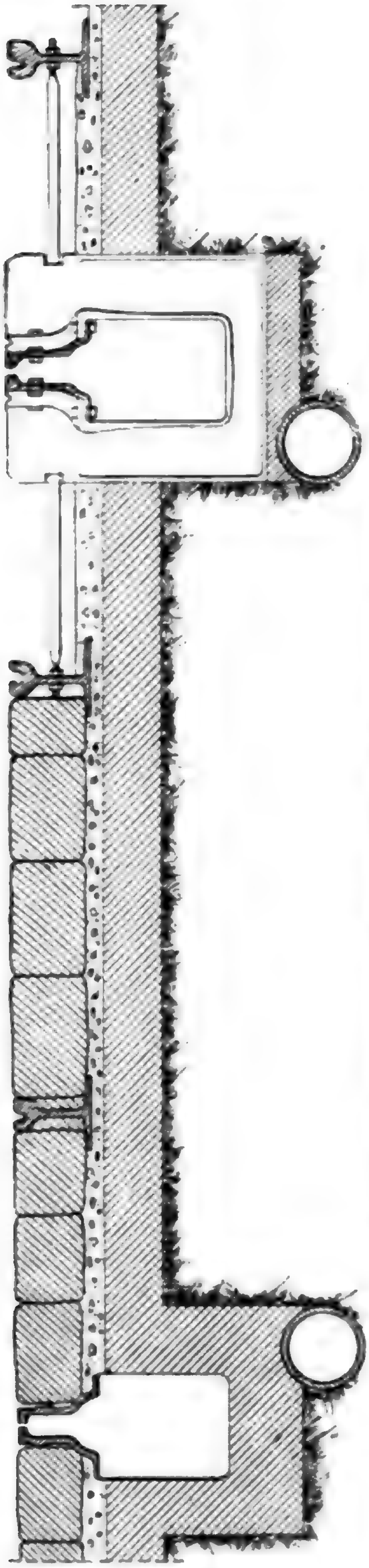


FIG. 318. Edinburgh Northern Cable Tramways: Transverse Section.

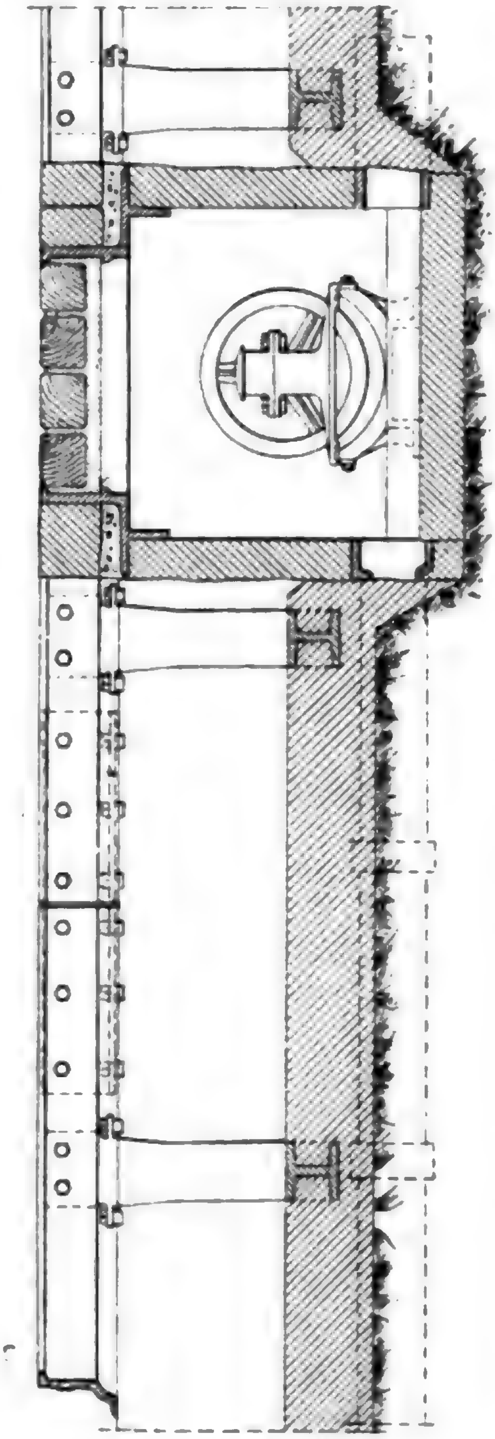


FIG. 319. Edinburgh Northern Cable Tramways: Longitudinal Section.

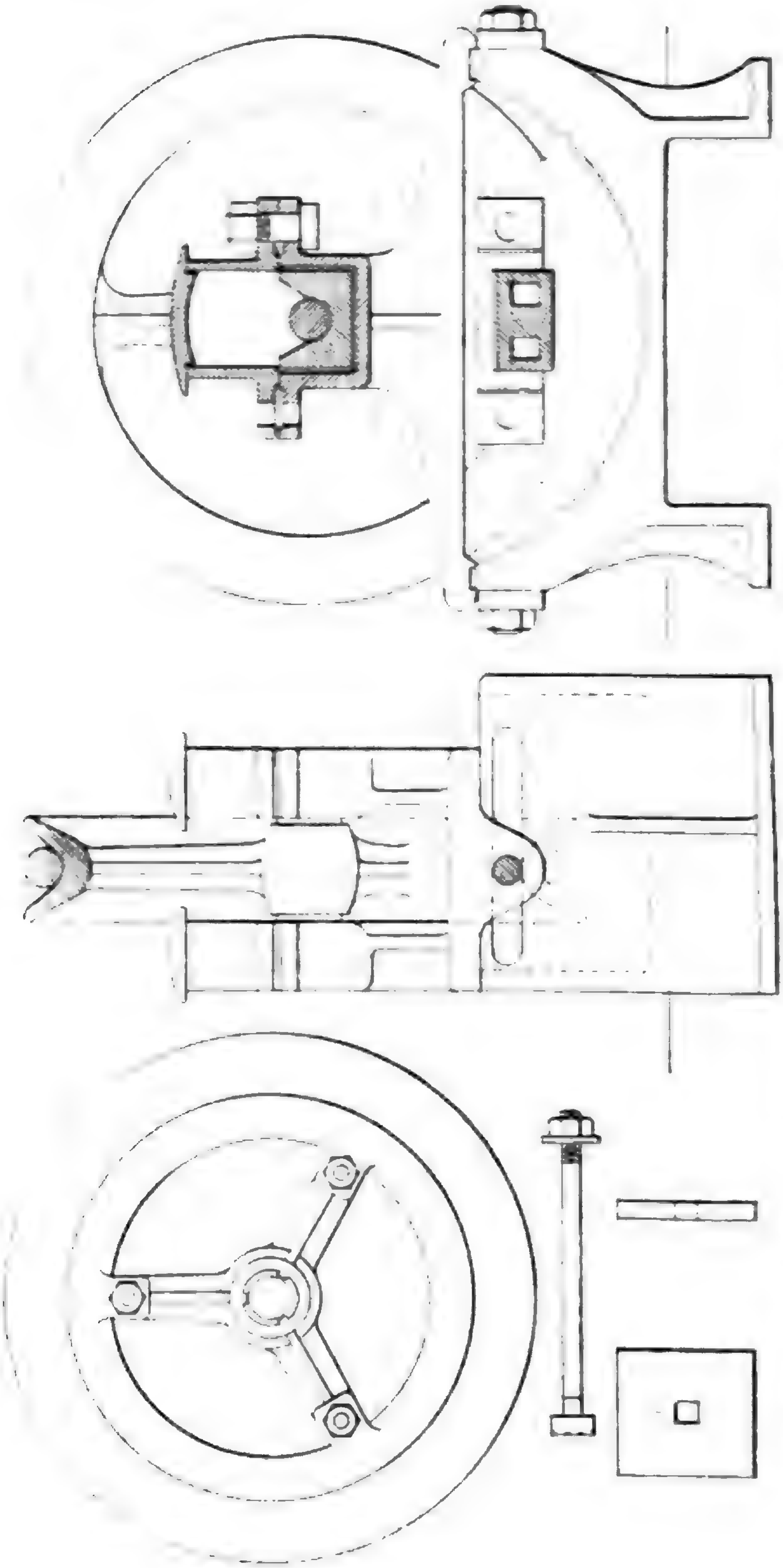


FIG. 320. Edinburgh Northern Cable Tramways: Supporting Pulleys for Cable (Colam's Patent).

weighing 75 lbs. per yard. The slot-rails are fished with plates weighing 34 lbs. each. They are tied to the running rails by adjustable bars to keep these accurately in gauge with the slot. The supporting pulleys, Fig. 320, are of cast iron, 14 inches in diameter, V-shaped in the tread. The journals revolve in boxed lignum-vitæ bearings. The horizontal supporting pulleys for curves, Fig. 321, are 14 inches in diameter. The large diverting pulleys are of cast iron; the jaws are bolted on in segments, with good treads. The terminal pits, Figs. 322 and 323, holding the diverting pulleys, are, one of brick, the other of concrete. They are 19 feet long, 11 feet broad, 8 feet deep. The roofing is constructed of rolled joints, jack arches, and buckled plates.

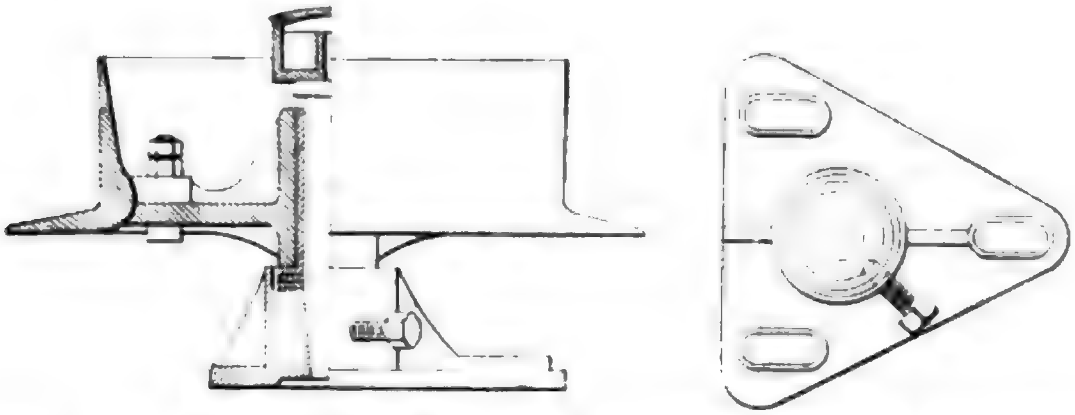


FIG. 321. Edinburgh Northern Cable Tramways: Horizontal Supporting Pulley, on curves.

The cables are those known as the Lang lay. This rope gives a maximum quantity of wear without fracture of wires, as it admits of the use of comparatively larger wires, and is, at least, as flexible as the older system. The rope is of crucible or steel wire laid round a hempen core, in 6 strands, each of 13 wires—7 round 6. The wires have stood a tensile stress of 80 tons per square inch, and torsional tests of 35 twists in 8 inches of length. The lay of the rope is 9 inches, the circumference is 3¼ inches, and the diameter is 1·03 inches.

The gripper, with details, is shown in Fig. 324. "The driver, in operating the hand-wheel, raises or lowers a nut by the square-thread spindle. Attached to the nut are two rods which raise or lower the bottom jaw of the gripper, the upper portions of which slide through openings in the plate, which has the upper jaw casting bolted to it. This plate rests on angles suspended

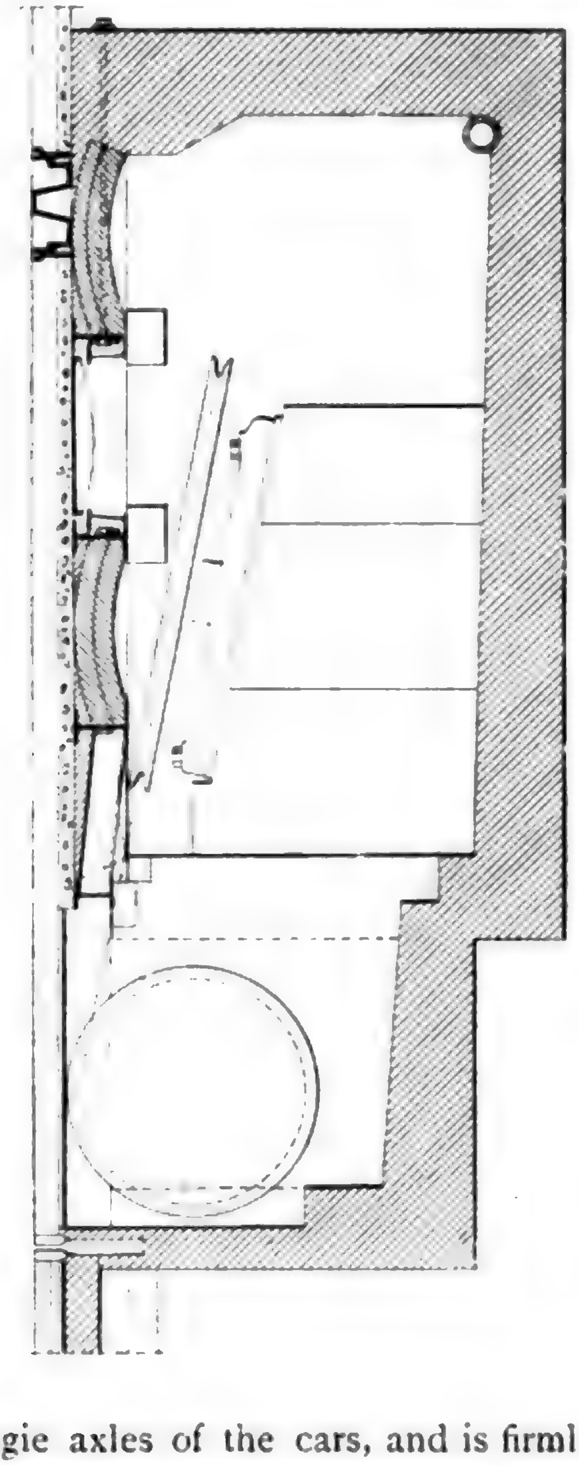


FIG. 322. Edinburgh Northern Cable Tramways: Terminal Pits and Diverting Pulleys.—Vertical section.

from the bogie axles of the cars, and is firmly held down in its place by wedges which are forced in or out by the driver through screw spindles and inclined slots. When the wedges are withdrawn the whole gripper will rise by the action of the hand-wheel. The bottom jaw can be lowered out 6 inches, and by that means the cable can be picked up, because when the rounded bottom of the jaw touches it, the cable ascends into its place in the gripper.

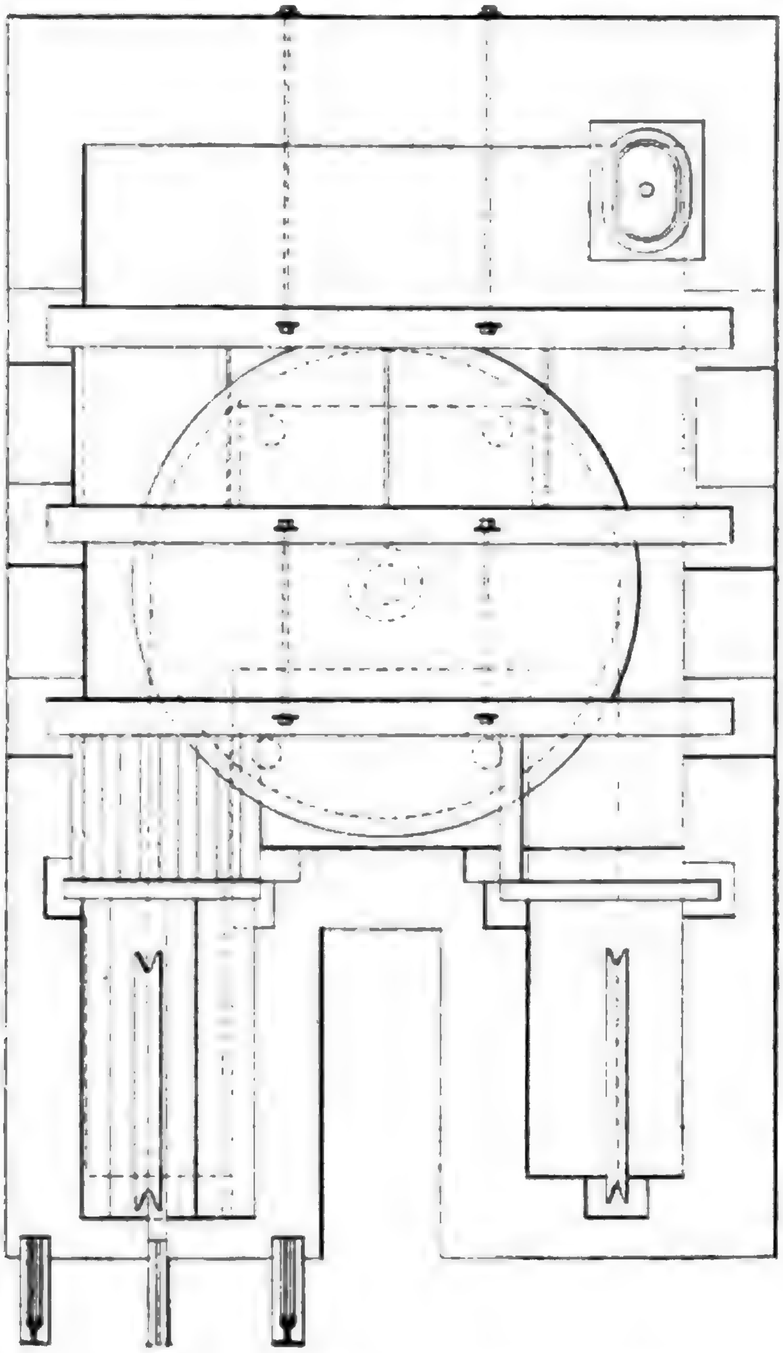


FIG. 323. Edinburgh Northern Cable Tramways: Terminal Pits and Diverting Pulleys.—Plan.

The dies by which the cable is gripped, are of the softest cast-iron, and they last on an average about six weeks. The sectional area of the steel shanks where they work in the slot is 4·92 square inches."

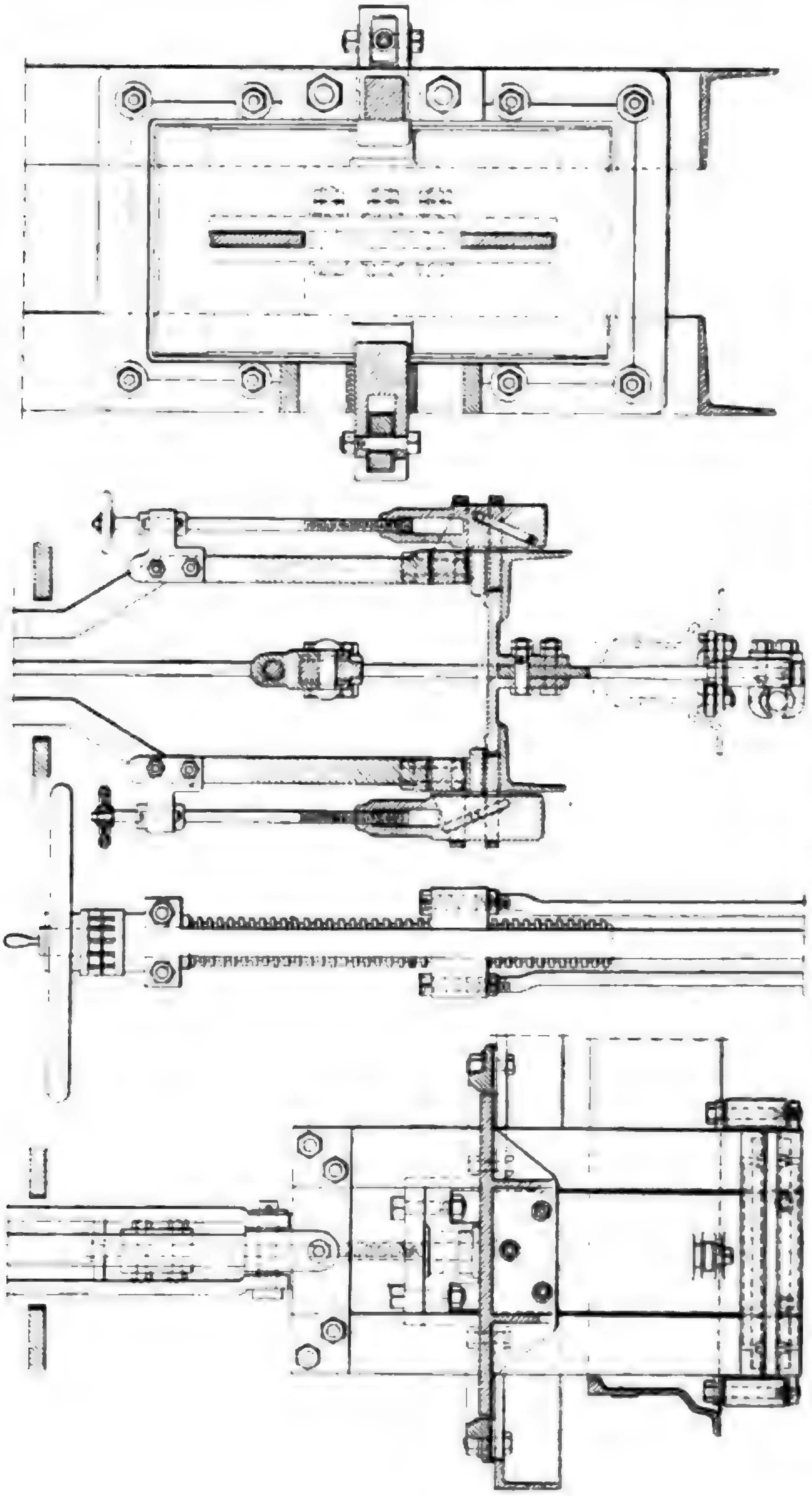


FIG. 324. Edinburgh Northern Cable Tramways : Gripper (Colam's Patent).

The cable is driven by a pair of horizontal non-condensing steam-engines, having 20-inch cylinders, with a stroke of 40 inches. The Proell automatic expansion gear is employed. Either engine is capable of working the two routes, and one of the routes can be thrown off without interfering with the other. The driving pulley is 10½ feet in diameter, having a V-groove. The jaw of the pulley is removable in segments, and is lined with white metal, which is renewed when the groove wears to the bottom. The bottom of the V is filled with soft wood upon which the cable bottoms. The cable, on entering the engine-house, goes direct to the driving-pulley, on which it makes a three-quarter turn, and thence passes over a 10-feet pulley to the automatic tension-pulley, around which it takes a half-turn when it leaves the engine-house. The effective tensional weight is 7 cwt.

Mr. Colam summarises the working conditions as follows:—On gradients as steep as 1 in 11; over perfectly flat roads; round small right-angled curves; over old bridges, in which the crowns are not twelve inches from the road surfaces; two routes at considerable distances apart, worked from one engine in the same depôt; single lines with passing places; reduced speeds by auxiliary cables, when it is necessary to go round dangerous corners.

The cost of constructing and equipping these lines for a three-minutes service of cars has been as follows:

	£	s.	d.
Track with tube, pulleys, &c., complete	33,377	0	0
Machinery buildings, offices, chimney shaft, &c.	4,786	0	0
Engines, boilers, machinery at depôt and in pits	5,103	0	0
Cars and gripping machinery	4,704	0	0
Auxiliary cable gear	850	0	0
Cables	1,260	0	0
Payments made to City for paving up to side walks, and to gas and water companies, and extras	7,150	0	0
	£57,230	0	0

The cost is at the rate of £9,867 per mile of single track, including equipment for three-minutes service of cars.

COMPARISONS OF RECEIPTS AND EXPENDITURES TAKEN FROM THE COMPANY'S BALANCE SHEETS FOR 1890, WITH 1893.

	Per mile run.	Year ending 1890.			Per mile run.	Year ending 1893		
	d.	£	s.	d.	d.	£	s.	d.
Receipts	12·46	12,345	14	6	11·41	15,275	14	0
Expenditures including—Motive power, traffics maintenance, and general charges .	8·93	8,284	0	9	6·38	8,431	3	7
Balance to nett revenue .		£4,061	13	9		£6,844	10	5

COMPARISON OF PASSENGERS CARRIED AND MILES RUN TAKEN FROM THE COMPANY'S BALANCE SHEETS FOR 1890, WITH 1893.

	Miles run.	Passengers carried.
For twelve months ending December, 1890 .	222,822	2,581,994
" " " 1893 .	316,752	3,263,790
Increase	93,930	681,796

NOTE.—These 93,930 extra miles were run, and the 681,796 extra passengers were carried at an increased expenditure, as indicated above, of the comparatively small sum of £147 2s. 10d.

Following on their experience of the working of the Edinburgh Northern tramways for a period of six years, the Edinburgh Corporation have lately purchased the horse tramway lines within their city boundaries, and have determined to work them by cable traction. For this purpose they have leased the lines to Messrs. Dick, Kerr & Co. for a period of twenty-one years. Practically, therefore, the whole system will in due course be converted and worked by means of cables.

It may also be noted that the tramway committee of the Newcastle Corporation have made a report in favour of the working of their system by cable traction, and there is little doubt that cables will soon be laid in that city. Other cities are enquiring in the same direction, and awakening to a knowledge of the advantages of the cable system, and its capacity for dealing with their heavy traffics: facts which for a considerable period have been fully appreciated by the cities of America and Australia, where heavy traffics have had to be negotiated.

BIRMINGHAM CABLE TRAMWAY.

The Birmingham Cable Tramway—a section of the Birmingham Central Tramways—was constructed between Colmore Row, Birmingham, and Hockley, to the designs of Mr. Joseph Kincaid and Mr. E. Pritchard, the engineers of the line; and was opened in March, 1888. Fig. 325 is a plan of the Birmingham terminus in Colmore Row, showing two lines of way, connected by two over-crossings, with the position of the large terminal pulley and pulley-pit. The pulley and its dispositions are shown in Fig. 326. So also are the four large pulleys and pulley-pit at Hockley in Figs. 327, 328, and 329, which receive the ropes on their way to Birmingham, and those for working the line from Hockley to Handsworth. A longitudinal section of the engine-house and tensional gear is given in Fig. 330. The rope coming from Birmingham enters the engine-house at a low level, and passes under and free of the first driving-pulley to the second driving-pulley, by which it is received, and round which it is bent, whence it passes over the top, then crossing over to and winding under the first pulley. Thence the rope, passing from the top of the first pulley, proceeds to and passes over and under the pulley on the tension-carriage, from which it returns to the engine-house, and passes out for Birmingham. The axle of the tension-pulley is not horizontal, and the pulley is inclined. By

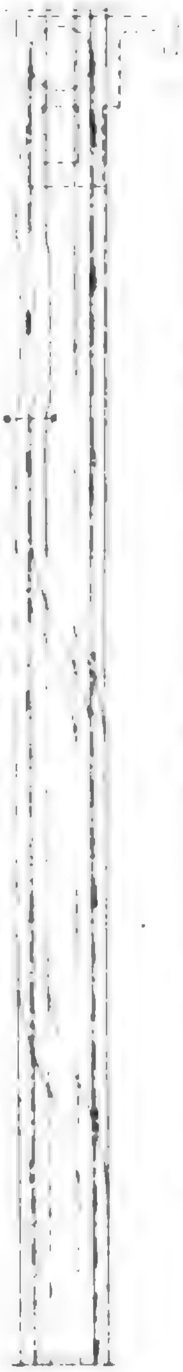


FIG. 325.—Birmingham Cable Tramway: Birmingham Terminus.

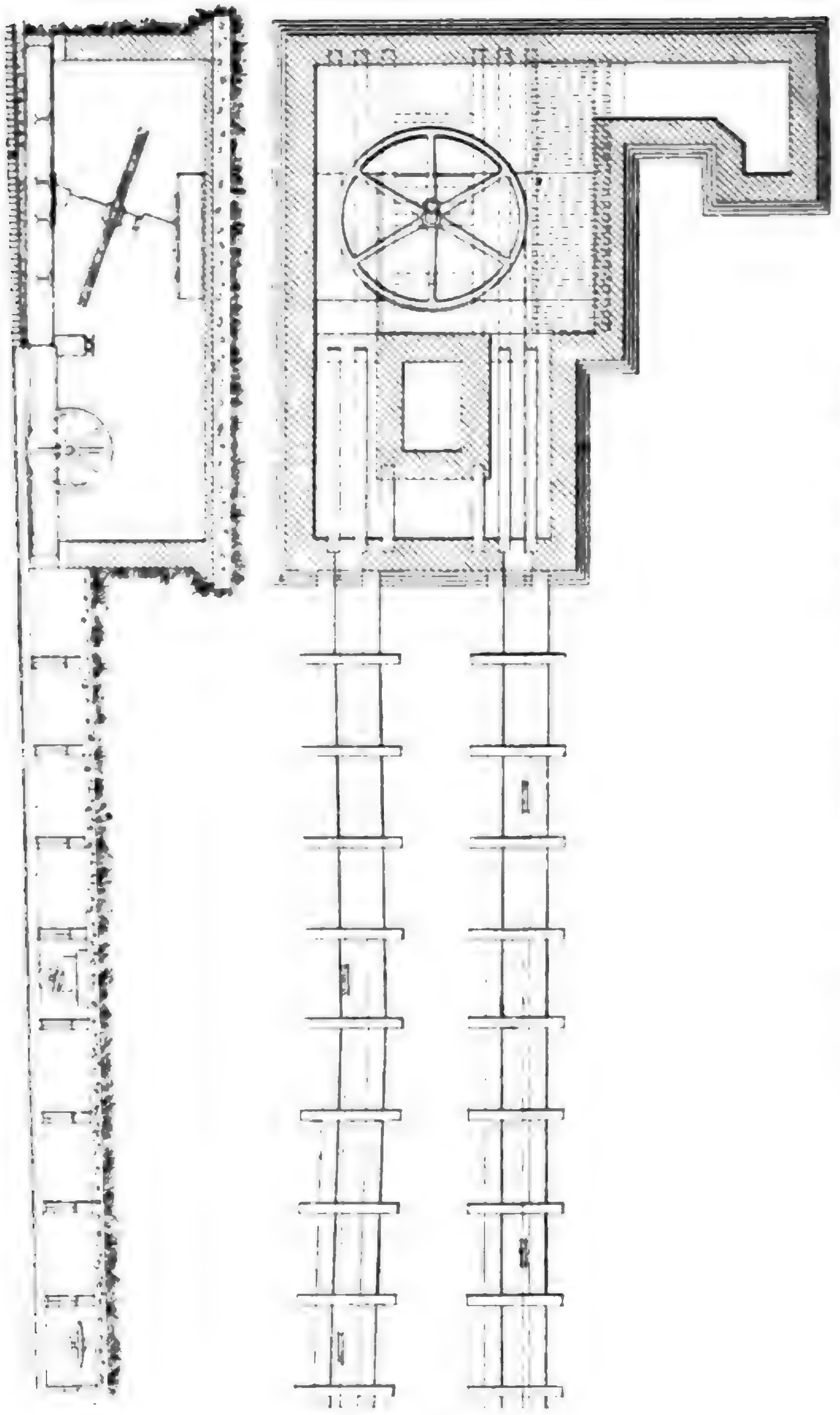


FIG. 326. Birmingham Cable Tramway: Terminal Pulley and Pit.

this means the rope coming from under the pulley is diverted to one side a little, and passes by the side of the driving-pulleys in the engine-house. The same system of communication is employed for the Handsworth line.

A winch is mounted on the tension-carriage, from which a rope is led to a small pulley fixed to a cross-head, then round the small pulley and back to the winch. Strong volute springs are fixed at the back of the cross-head to take up or absorb any violent shock. From this point chains are led over the pulleys and supports, and connected to cradles, in which the tension-weights are carried. There are 16 weights adjustable in number according to the magnitude of the traffic or the condition of the rails.

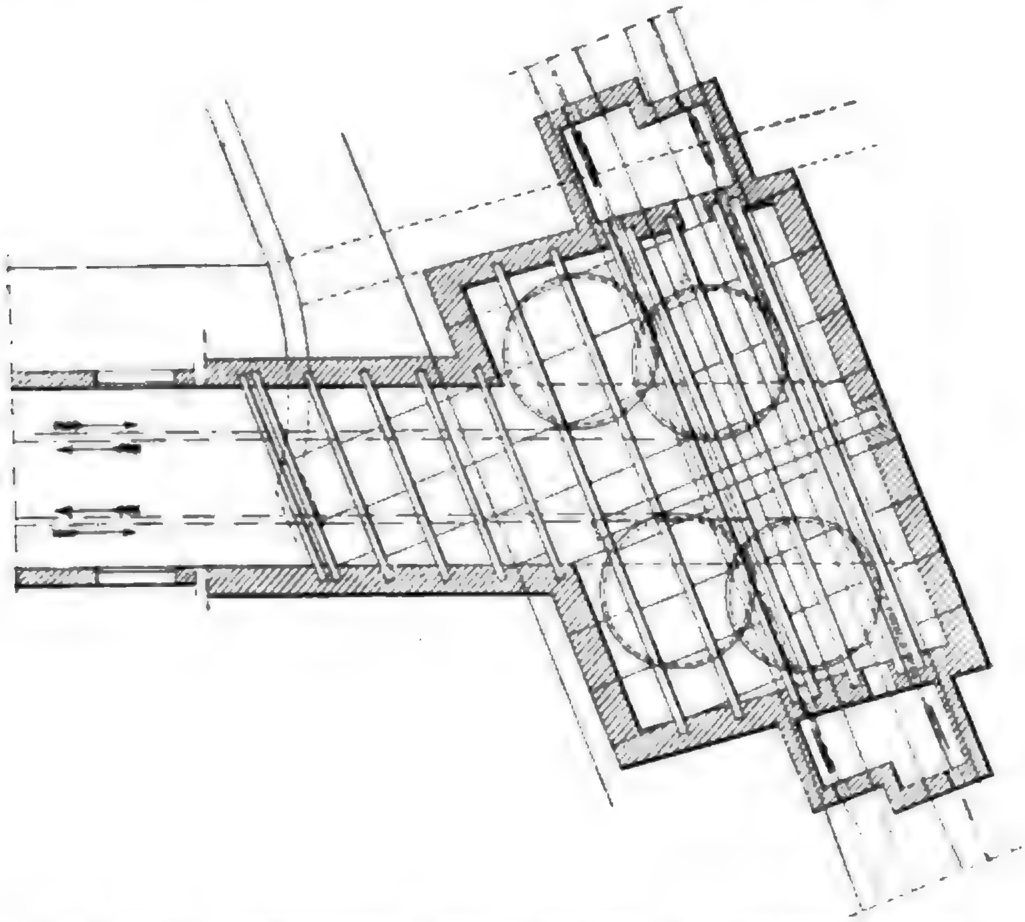


FIG. 327. Birmingham Cable Tramway: Pulleys and Pulley Pit at Hockley.

The line is worked by steam-power, for which steam is supplied by six Lancashire boilers, 6 feet in diameter, 24 feet long,

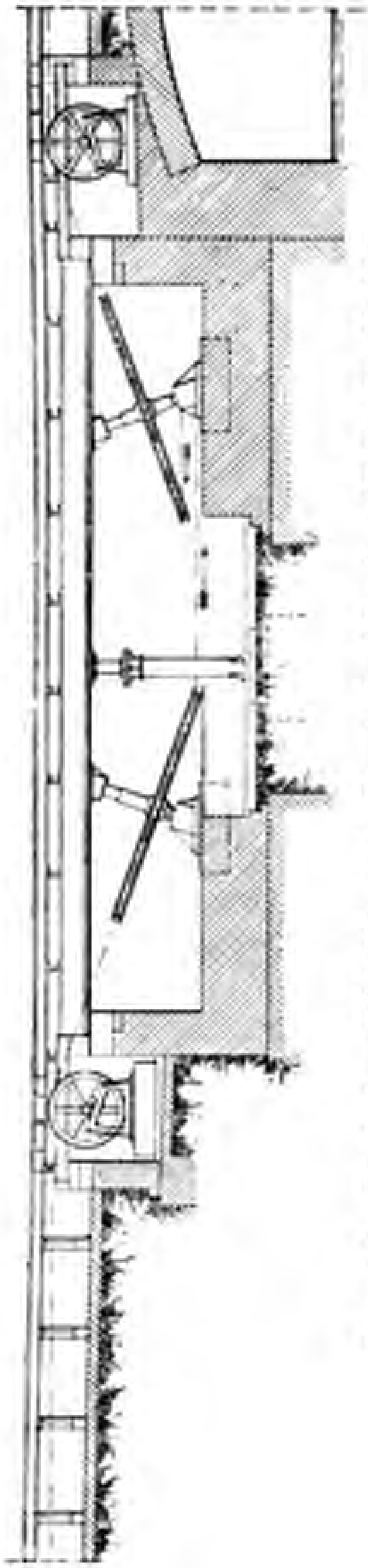


FIG. 328. Birmingham Cable Tramway: Longitudinal Section of Pulley Pit, Hockley.

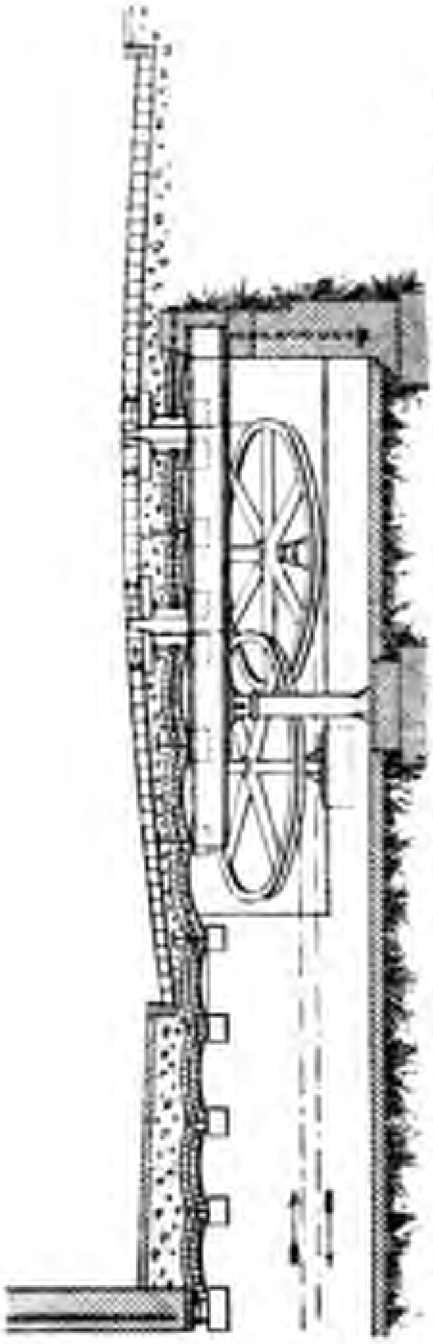


FIG. 329. Birmingham Cable Tramway: Transverse Section of Pulley Pit, Hockley.

with two flues 28¼ inches in diameter, generating steam of 80 lbs. pressure per square inch. The two flues merge in one wide flue, which is fitted with 21 Galloway tubes. The chimney is 110 feet high above the ground level, and 5½ feet in diameter at the top.

The engines, Figs. 331 and 332, are a pair of horizontal steam-engines, having jacketed cylinders, 24 inches in diameter, with a common stroke of 4 feet, making 50 revolutions per minute. The fly-wheels are 15 feet in diameter, 2 feet wide, and weigh about 8 tons each. Under each fly-wheel a powerful steam-brake is fixed, and the engines can be stopped immediately in case of accident to the rope. The main shaft is of steel, having 9¼ inch journals. The pinion on the main shaft is 5 feet 4⅝ inches in diameter, and gears into the front driving spur-wheel, which is 13 feet 11⅛ inches in diameter. The back driver, of equal diameter, gears with and is driven by the front driver. Either engine can be coupled or uncoupled as required by means of clutches on the engine-shaft. The three spur-wheels are keyed fast on the shafts, but the large grooved pulleys are made fast or loose on the spur-wheel shafts by means of clutches and hand-wheels on the ends. The lower of the rope-driving pulleys are 10 feet in diameter. They are for the Birmingham service. The periphery is

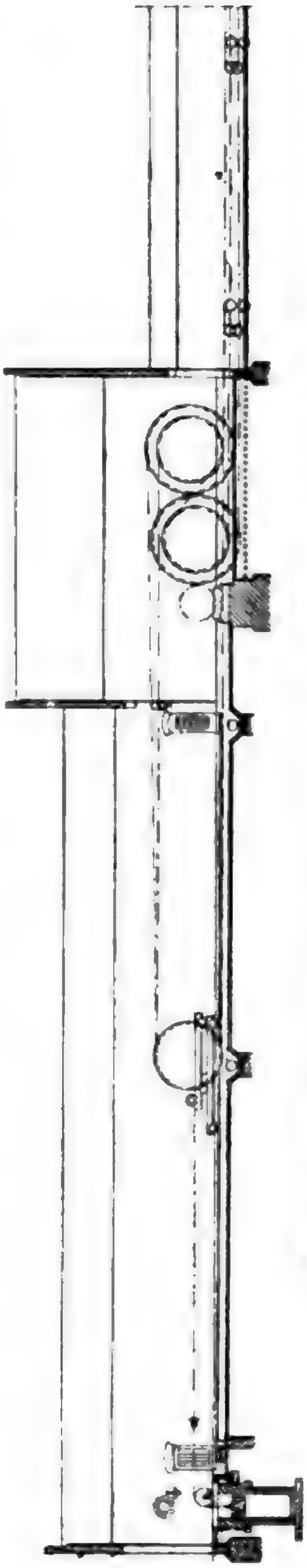


FIG. 330. Birmingham Cable Tramway: Engine House and Tensional Gear.

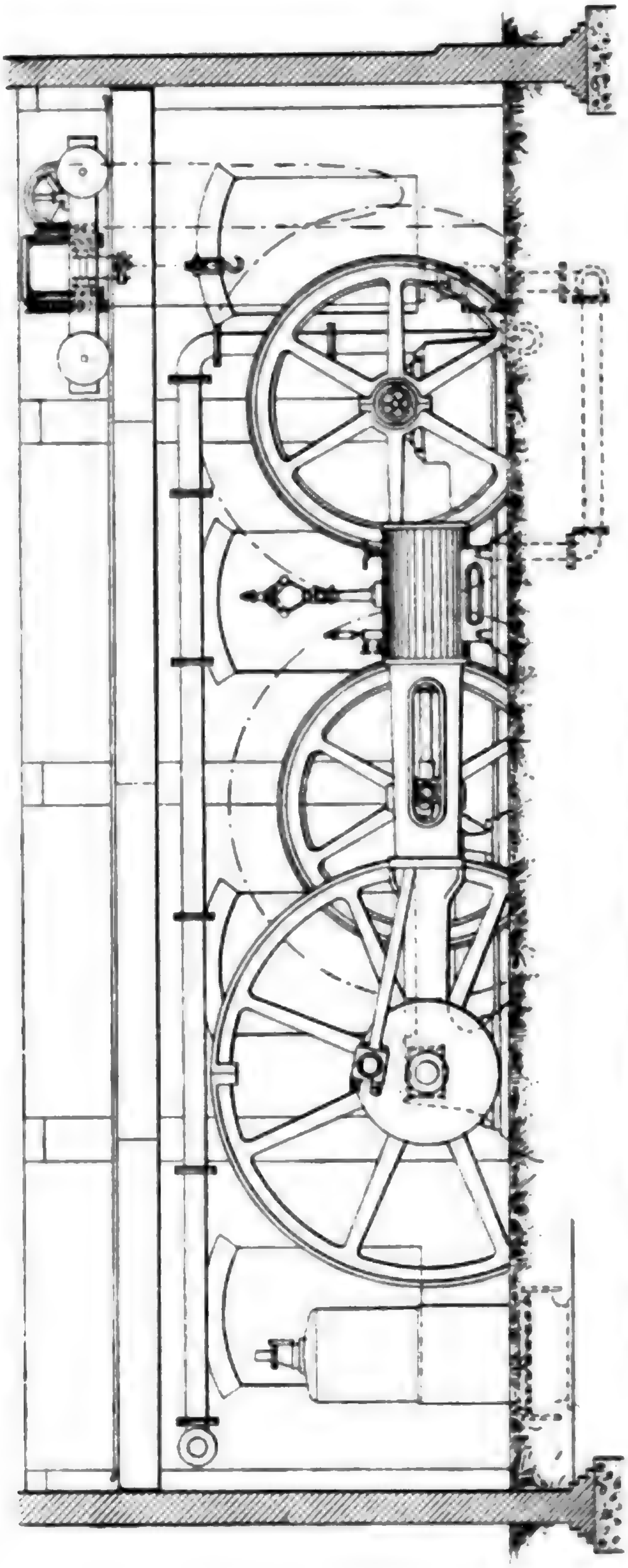


FIG. 331. Birmingham Cable Tramway: Steam Engine and Driving Gear.—Elevation.

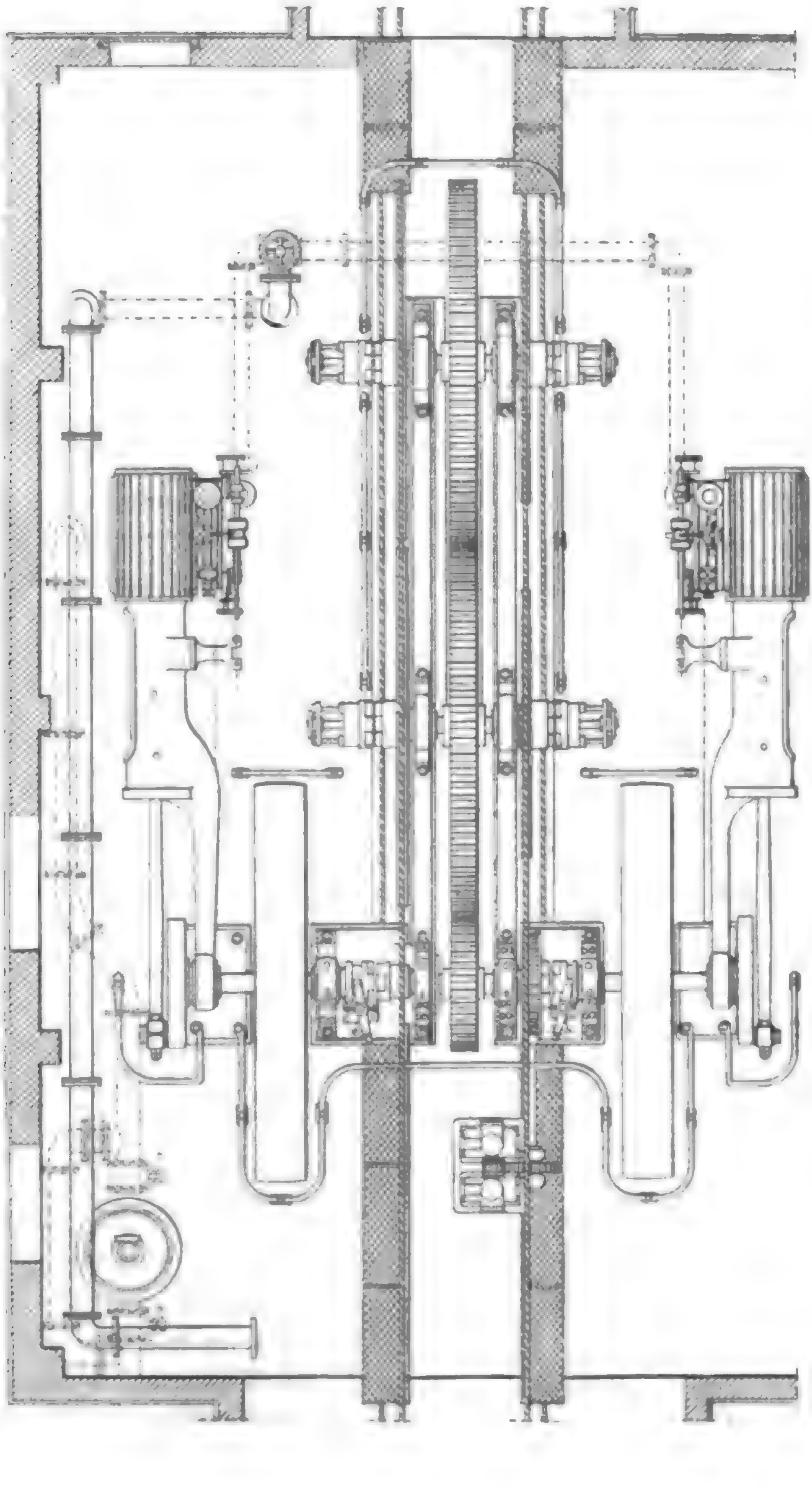


FIG. 332. **Birmingham Cable Tramway: Steam Engine and Driving Gear.—Plan.**

grooved for the rope, and is lined with compressed beech-wood, held in position by segments bolted on at one side, as shown in Fig. 333. The upper of the large grooved pulleys, 13 feet 4 inches in diameter, are employed on the Handsworth service. The larger size was adopted because the cars may be run on this service at a higher speed.

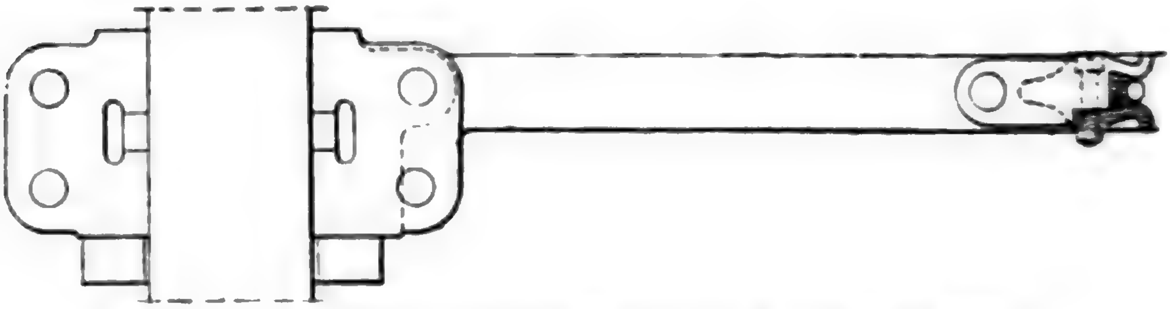


FIG. 333. Birmingham Cable Tramway: Rope-driving Pulley.

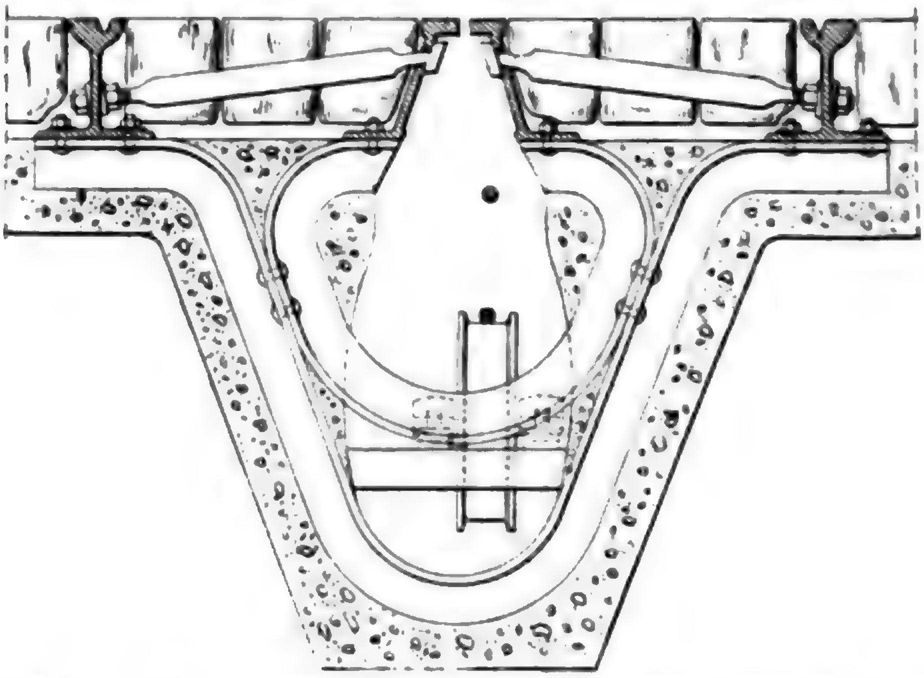


FIG. 334. Birmingham Cable Tramway: Type Section of Way.

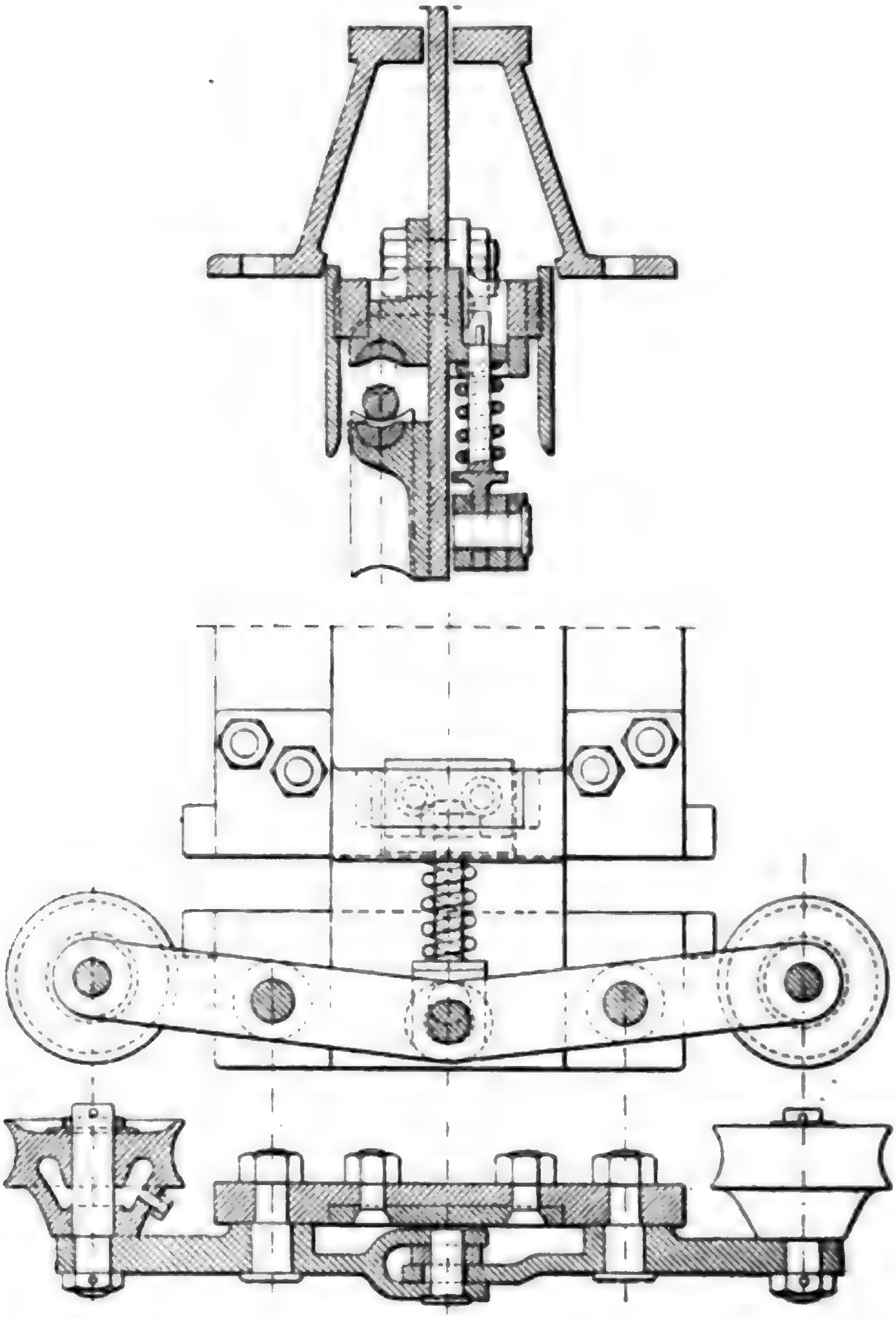
The cars are constructed with two bogies. They can carry 20 passengers inside and 21 outside; together, 41 passengers.

A cross section, typical of the whole of the way, is given in Fig. 334. The gauge is 3½ feet. The running rails are of girder section, weighing 98 lbs. per yard, the slot rails are 65 lbs. per yard. The conduit is of concrete, in which the framed bearers of the rails, running and slot, with the ordinary conduit-pulley supports, are embedded. The conduit is 13 inches wide, and 2 feet 8 inches deep below the level of the rails. The framing, or skeleton of the conduit, is constructed of T-steel, 4 inches by 3 inches by ⅜ inch. The frames or yokes are 4 feet apart between centres. The carrying-pulleys, in the lower part of the conduit, for supporting the rope, are 11½ inches in diameter, 3 inches wide.

The cable is of steel wire, 3⅜ inches in circumference, or about 1·08 inches in diameter. The cable contains 6 strands of 19 wires each, laid on a central hemp-core. The wire is No. 15 wire gauge. The breaking tensile strength of all except the central wire of each strand is 95 tons per square inch, and the breaking strength of each cable is 33 tons.

The gripper, with its mounting, is shown in Figs. 335 and 336. Its position relative to the slot-rails is shown in Fig. 335, the upper part of the figure showing the slot-rails in section. When the gripper jaws are open, and the cable runs freely between them, it is carried by the smaller rollers, which are carried by levers, which work on the pins, as fulcra, and are connected by a pin, which causes them to act in concert either in raising or in lowering the rope, and so fixing or freeing it. When the lower jaw descends, with the vertically sliding plate to which it is fixed, the helical spring, acting vertically under compression through the pin and levers, forces the rollers upwards into the positions shown. The gripper-plate slides between guide-plates. By reverse movements the rope is lifted on the lower jaw into gripping position. The raising and lowering of the gripper apparatus is effected by means of the grip-lever on the platform of the car. The rope is shown in section in the two extreme positions in Fig. 334; the upper position when gripped, the lower when running free.

The cable tramway, as above described, has been extended from the Hockley winding station on a route three miles long with double way, worked by ropes from the Hockley station.



FIGS. 335 and 336—Birmingham Cable Tramway: Gripper.

MATLOCK CABLE TRAMWAY.

The Matlock Cable Tramway, opened in Easter, 1893, is a short line ⅜ mile in length, presenting unique features of construction and application much appreciated by the residents in the district. The track is all single line, with one passing place, and on the single line are six curves from 180 feet to 1,000 feet in radius. The average gradient is 1 in 7·7, and the steepest is 1 in 5. There is a rise of 300 feet in 770 yards. The width of road is in many places only 20 feet. Car brakes are provided of sufficient power to stop a loaded car on the steepest grade when running free after having left the cable. Each car is provided with two brakes, a wheel and a rail brake. The construction of the track is similar to that of the Edinburgh Northern Cable Tramways, but special pulleys were designed to take the cable round the curves. The gauge of the way is 3½ feet. The speed of the rope is 5½ miles per hour.

The driving plant at the depôt is in duplicate, and consists of two Sinclair boilers fitted with mechanical stokers, and a pair of high-pressure steam-engines with cylinders of 14 inches diameter and 28-inch stroke, with Proell valve gear. The grip pulley, cable gearing, and car grippers are similar to those supplied for the Edinburgh cable lines. The cars are double-deckers, and have garden seats both inside and outside, seating 31 passengers. The whole of the permanent way, engines, boilers, cars, and cables were provided through Messrs. Dick, Kerr & Co. to the designs of Mr. W. N. Colam. Mr. Croydon Marks was engineer to the company.

BRIXTON CABLE ROUTE OF THE LONDON TRAMWAYS.

The Brixton Cable Tramway of the London Tramways Company has a track length of 5½ miles, to a gauge of 4 feet 8½ inches; and runs from near Kennington Park through the busy thoroughfares of Brixton, up Streatham-hill to a point near Streatham-hill Station. The depôt, situated at the Streatham terminus, is of large dimensions, covering a piece of ground 370 feet by 110 feet. Its arrangement is shown in detail in Figs. 337 to 339

(Plates V. and VI.). It was built to accommodate the machinery and cars necessary for working an extension of the line to Streatham Common: a further distance of about three miles of route. The London tramway line was opened for horse traffic about the year 1875; and the cable tramway from Kennington to Telford Park, in December, 1892.

The cable, about six miles in length in one rope, was manufactured of special steel, and it weighs about 30 tons. It runs along the road in a concrete tube, constructed centrally along both up and down tracks, somewhat similar to the arrangement in the case of the Edinburgh tramway shown in Figs. 318 and 319 (page 535). The tube, which is properly drained, is 19 inches deep and 9 inches wide. In the road, however, there is but a continuous slot ⅝ inch wide; this slot being formed by rolled steel slot-rails fixed to cast-iron yokes embedded in concrete. The speed of the cable is 8 miles per hour.

In the tube on the straight road, at intervals of about 50 feet, vertical pulleys, as in Fig. 320, are placed, and on the curves horizontal pulleys (Fig. 321), at intervals proportionate to the curves. These pulleys carry the cable so that normally it is from 1½ inches to 2½ inches out of the centre line of the slot: no road dirt, therefore, falling on it.

Over each pulley a hatch cover (Fig. 319) 18 inches by 9 inches, is placed in the road. This cover is fitted with wood blocks, and is very little distinguishable from the ordinary paving.

At the Kennington terminus, large pulleys are provided for the purpose of passing the cable from the up line to the down line, similar to Fig. 322 (p. 538). At Streatham, similar pulleys are provided to pass the cable into the depôt.

Ordinary horse cars are employed on the line for passenger traffic, coupled to a cable car for the purposes of cable traction. On the cable car the gripping apparatus is mounted. Such a disposition was rendered necessary by the fact that at Kennington the passenger cars are despatched to three different termini by means of horses, and it was thought undesirable to increase the weight of their cars by the gripping apparatus. The cable cars

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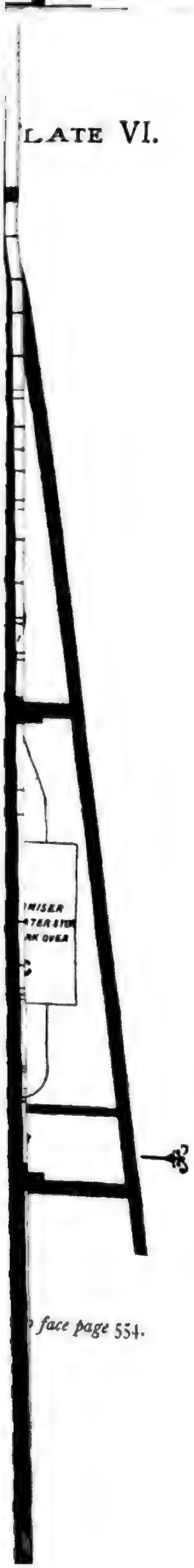
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simply carry the gripper and the driver, the Board of Trade objecting to their carrying passengers until after the line had been in operation for some time.

Each cable car is provided with a double-jawed gripper, somewhat similar to Fig. 324—that is, a gripper which is capable of use on both the up and the down lines. The gripper is suspended from the car framing in such a way that it is free to move from left to right: a movement which is necessary when rounding the curves in the slot. The shank, which is 12 inches wide and ½ inch thick, passes through the slot, and is fitted with upper and lower jaws for gripping the cable. The upper jaw maintains a fixed level in the tube; whilst the lower jaw can be raised or lowered by means of the hand-wheel and screw, as seen, above the car floor, to the extent of 6 inches, thus rendering it possible to pick up the cable at any part of the road. Both jaws are lined with soft cast-iron dies, which are easily renewable. In rounding curves in the road a horizontal roller is provided in the gripper shank, and this then rolls on a recess in the slot rail.

There are four double-furnace Babcock & Wilcox water-tube boilers, having a working pressure of 140 lbs. per square inch. They are provided with Vicars' mechanical stokers and coal elevators; also an automatic arrangement for maintaining the steam steadily at one pressure without interference on the part of the man in charge. The arrangement is worked by a jet of steam from the boiler in such a way that as the pressure rises above the normal working pressure the stokers are stopped, and when it falls the stokers go on. Rain-water is collected in settling-tanks.

The engines for driving the line are in duplicate. There are two pairs of high-pressure compound steam-engines with high-pressure cylinders of 20 inches, and low-pressure cylinders of 32 inches in diameter respectively, and the stroke of both is 50 inches. Each pair of engines is capable of driving 12 miles of cable with the necessary cars, and is now developing about half its maximum power, the high-pressure cylinders alone being used. One pair of engines is placed at each end of the first motion-shaft, the two cylinders driving on to a U crank and a disc crank respectively. The valve gear on the high-pressure cylinders is of the Proell type; the low-pressure cylinders are fitted with Corliss valves. The motion of the engines is communicated to the counter or cable shaft by means of a rope-drive, which forms the chief feature of novelty in the engine-house. The ratio of the gearing is three to one, and the large wheel on the countershaft is 30 feet diameter. Each wheel is grooved for twenty-four 6¼-inch ropes, 2 inches in diameter.

A rope drive was installed instead of gearing in order to insure a minimum of vibration and noise, the depôt being built in a residential neighbourhood.

At one end of the countershaft is a Mather & Platt clutch of the outside grip pattern, which can be worked by means of a lever placed near the engine stop-valve, thus insuring complete control of the machinery from one point. The clutch communicates the motion of the countershaft to the grip pulley, the pulley which moves the cable. A similar clutch and pulley are to be placed on the other end of the countershaft to drive the second cable when the extensions are made. The grip pulley is of the solid jaw type; the jaw being a parallel groove running round the pulley, the cable resting on a small shoulder on either side of the jaw. The jaw, formed of white metal slabs cast in place, and renewable, is found not to do any harm to the cable. This method of drive should be contrasted with the present American practice—two Walker differential drums having three or four complete wraps of the cable, whereas a three-quarter lap is found to do the work in London, and has been found equal to any strain put on it. The cable, after leaving the grip pulley, is conducted by another wheel to the tension pulley, which is mounted on a wrought-iron carriage free to run on rails. A uniform tension is maintained on the cable by a weight suspended from the back of the tension carriage. The rise or fall of this weight is a perfect indicator of the amount of strain on the cable, and by watching its movements a very good idea may be gained of the fluctuations of the load which have to be provided for in a cable tramway, in order to insure the smooth and steady running of the cars on the road.

The depôt is built on a level 10 feet above the level of the main road, and the cars in returning to the shed have to mount a long incline of 1 in 20. An auxiliary rope is provided here, which is driven by a clutch on the countershaft, at a speed of about 2½ miles per hour. It is so arranged that the cars can take this rope on the main line, mount the incline, and pass on to a traverser which commands the whole width of the car-shed, and is moved by another rope off the main engines.

Machinery is provided for changing the cables on the main line, together with the necessary storage drums. Machines are also provided for doing all necessary repairs, such as slotting, planing, drilling, turning. The necessary power for driving all this machinery is obtained from the barring engine.

A travelling crane is provided; of 55 feet span to lift 24 tons on two winches. This crane travels the whole length of the engine-house, which is 150 feet.

Mr. W. N. Colam was the engineer for the whole of the work, including the buildings; Messrs. Dick, Kerr & Co. were the contractors for the road, gripping gear, engines, and most of the machinery; Messrs. Babcock & Wilcox supplied the boilers; Messrs. Cradock & Co. the cable; and Messrs. Lucas & Aird the buildings.

The Company possess in their Brixton route one of the most complete installations for cable traction. They have applied to Parliament for an extension.

PART VI.

ELECTRIC TRACTION.

CHAPTER I.

ELECTRIC POWER AS APPLIED TO TRAMWAYS.

THE only available source of electrical energy was until comparatively recently the galvanic battery, and attempts have been made, since the beginning of the century, to apply that force for obtaining and transmitting power. The hopelessness of the attempts is obvious. A pound of zinc is produced by the combustion of from 15 lbs. to 20 lbs. of coal, and while a pound of coal in burning gives out 12,000 heat-units, a pound of zinc in burning gives only 2,340 units. Thus zinc gives in burning only one-fifth of the effect in energy that coal does, and taking the cost of zinc at fifty times that of coal, it follows that the cost of energy in the case of a galvanic battery is approximately two hundred and fifty times greater than in a steam boiler.

For the purpose of mechanical traction on tramways, electric power may be transformed into mechanical power, with a large percentage of efficiency. The dynamo is the source with which, principally, electricity has been associated. The current produced is known as inductional electricity, as it is magnetically induced by the revolution of the armature of the dynamo. The motor is connected to the wheels of the car, for the purpose of propulsion, by direct gearing or by reducing gear. Self-contained motor trucks comprise a rigid framework resting on the axle-boxes.

The body of the car rests on and is fastened to the frame. Thus may be provided an elastic gear connection ; the axle-journals are maintained parallel; and the gear-wheels may be properly proportioned to reduce the speed of the armature from, say, 2,500 revolutions per minute, for a suitable speed of the car on the rails. In order to secure a sufficient degree of adhesion for propulsion, it is expedient to provide two motors to each truck, geared to independent axles.

To transmit current from the dynamo, or generator, to the motors on the car, it is necessary that a complete metallic circuit should extend from the generator to the car, and return to the generator. "Positive" current is conveyed over that part of the circuit which leads out from the generator. "Negative" current is the return current leading back to the generator.

It is readily seen that an electric motor can be connected by reducing gear to the wheels of a tram-car to cause them to revolve : in the manner of a turning-lathe, for instance. But the peculiar difficulty in dealing with electric traction is to convey the electricity produced at the supply station to the electric motor on the moving cars :—properly to locate these conductors, with the best means of securing a continuous movable contact.

(1.) On some early tramways, a third rail was laid, on insulating material, through which positive current was transmitted, and from which, by means of a brush or wheel, the current was taken up, passed through the motor, and thence, by means of the car-wheels, to the rails of the way, through which it was returned to the generator.

(2.) Underground communication by two wires or metal rods, one for positive current, the other for negative current, in a shallow conduit laid between the rails or at one side of the way. Contact with the conductor is effected by means of brushes or ploughs, supported by a thin iron plate or finger hung to the truck, and moving along a narrow longitudinal slot in the top of the conduit. One brush takes up current from the positive wire and conveys it to the motor, whence it is returned to the negative wire through the other brush. The conducting wires must be carefully insulated from the sides of the conduit, and from contact with the slot-rails.

(3.) The overhead system of connection is the system most generally employed. It includes the methods of (1) supporting one or both conductors on trolleys, and (2) making contact with them above the car. Of these, the single-wire under-contact arrangement is the more popular. The positive wire is supported over the centre of the way by means of cross wires attached to poles at the side of the street, or by means of cross-arms on poles placed between the ways. For single lines of way, side poles with brackets are used. The trolley wires are braced on curves.

In the single-trolley system, the rails are utilised for the return or negative current; and for this purpose the ends of the rails are wired together, and are usually supplemented by one or more return wires which are buried beneath the pavement, to which each section of rail or casting is connected by means of branch wires. The bonds are riveted to the rails. Galvanised iron wire is recommended for rail-bonds and way wiring. Copper wiring deteriorates rapidly by electrolysis.

The way connections should return the current to the generator in a direct path—having a minimum of resistance in the return circuit—and resulting in economy of power, and efficient service from the motors.

In some soils the resistance of the rail-return may be reduced and leakage avoided, by driving metal rods or pieces of gas pipe 10 or 15 feet down into the ground and connecting these rods with the rails or a supplementary wire.

In place of rods, copper ground plates, having from 30 to 40 sq. ft. of surface, may be placed at intervals of 1,000 feet, and at a depth sufficient to insure their being always in moist ground.

For supporting the overhead wire, poles of wood, iron, or steel, from 26 to 30 feet long, may be employed. The best timber is chestnut, cedar, or Georgia pine. Wooden poles on straight lines should be from 7 to 8 inches in diameter at the top, and at least from 10 to 12 inches at the base; but iron or steel poles are more desirable than wooden poles. The poles are usually placed

125 feet apart, and they should be set at least 6 feet deep in the ground in a foundation of concrete. Near the top of the pole a device should be provided to secure the most perfect insulation for the suspension wire. The trolley wire is supported from above without obstructing the passage of the under-running trolley wheel.

The trolley wire should not be smaller than No. 0 (·325 inch) of hard drawn copper wire or silicon bronze wire.

Feed Wire.—The trolley wire is usually not large enough to transmit the power to a long distance without undue loss; and it is advantageous to supply the current to the trolley wire at intervals, by means of auxiliary insulated feed wire. By this means a nearly uniform potential can be maintained at all points of the line. Subways, or electric conduits for feed wires, should be of non-conducting tubing, through which the bare conductors can be laid; and the tubing should be enclosed in a creosoted plank casing. Contact of the moving car with the overhead wire, for the purpose of conducting the current through the controlling mechanism on the car to the respective poles of the motor, is made by means of a trolley pole and stand. The relation of the cars to the circuit is illustrated by diagram, Fig. 340, showing that the current seems to start from the positive brush of the generator, G, and along the overhead conductor in the line of the arrows until it reaches the trolley, T, of one of the motor bars, which is in contact with the conductor. Here a portion of the current passes down through the trolley to the motors M, M, as shown by the dotted line. The current having done its work in the motors goes on the rails through the wheels and by the rails return wire, W, back to the negative brush of the generator. The main portion of the current, which divides at T, passes on to feed the other cars upon the line in the same manner, each car taking from the conductor only the necessary amount of current to develop the required power, while the entire return current is carried by the rail and a supplementary wire.

The trolley-stand consists of an upright, firmly attached to the roof of the car, and a long wooden or iron arm mast, pivoted near

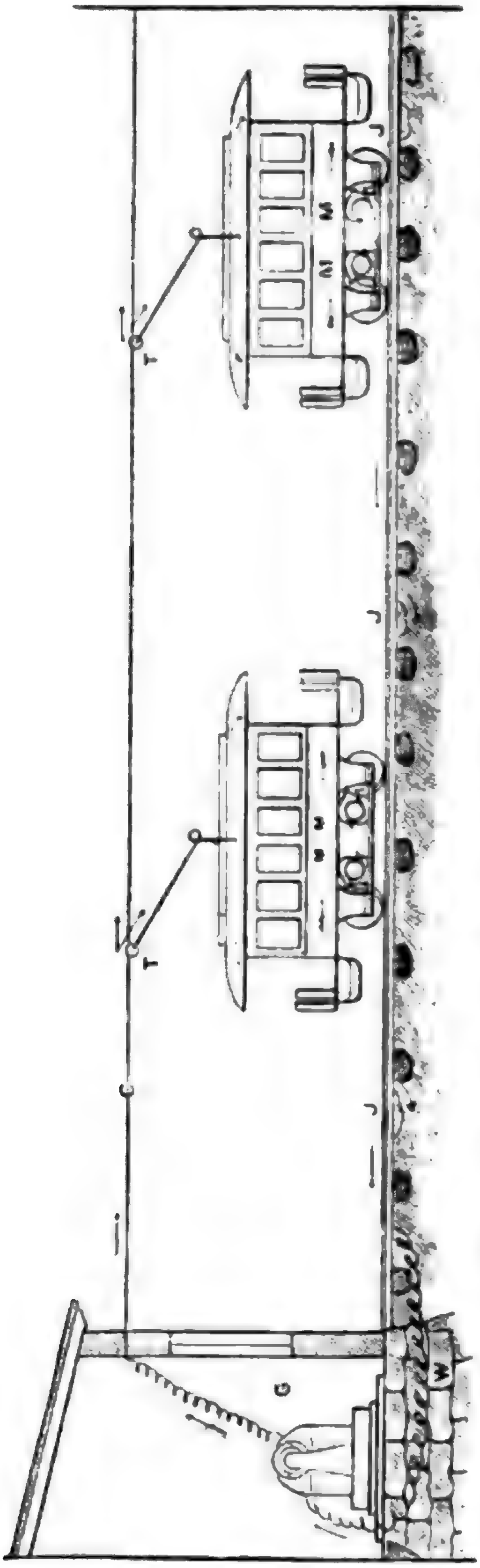

Fig. 340.—Electric Traction: Overhead Conductor System. Relation of the Cars to the Circuit.

one end upon the top of the upright. The long arm of the mast carries a metal trolley wheel which is held firmly up against the under side of the conductor by strong springs attached to the short end of the arm and connected with the base of the standard. The mast springs and attachments are all free to swivel upon the upright.

An insulated wire embedded in the mast conducts the current from the trolley wheel to the controlling switches on the car, but in place of a trolley wheel, a sliding contact may be obtained by means of a carbon-lined metal brush at the end of a trolley pole.

Two overhead wires, 5 inches or 6 inches apart, are, as already stated, sometimes employed instead of the single overhead wire and rail connections to form the necessary metal circuit. Two trolley wheels, or two masts, each carrying a wheel, are required, one wheel in contact with the positive wire and the other with the negative wire. The current is thus conducted from one wire to the motors and back to the other wire.

As to the wiring of the car, and how the wires are connected with the switches and with the poles of the motors. Usually a switch on each platform directs the current to both motors, and controls the speed and the direction of the car. In addition, the flow of current through the motors is controlled :—according to *one system*, by a peculiar winding of the field magnets ; by *another system*, current is controlled through a "rheostat," or resistance box, by which any abnormal flow of current through the armature is prevented, and the motor is enabled to start gradually. It is in the form of a half circle, mounted under the floor of the car. Resistance is produced by small pieces of thin sheet-iron, side by side, separated by mica, so arranged that they are connected in series throughout the rheostat. At proper intervals, contact pieces of heavy sheet-iron are provided. The whole is secured in a semi-circular iron case thoroughly insulated with mica throughout.

Storage Batteries, Accumulators, or Secondary Batteries, belong to a class of *chemical batteries*, in which chemical action, primarily induced by the application of a current of electricity, supplied from a primary battery or from a dynamo, enables a strong current to be given back any time after cutting off the charging current. This derived current is the product of chemical reaction.

The accumulator system of storage batteries, or secondary batteries, is the simplest and most convenient method of conveying the electricity produced at the supply station to the electric motor on the cars. The stored energy is carried in accumulators, which are placed under the seats of the car, and connected by wires through a regulating switch to the motor. But there is an unavoidable loss in the use of current taken from accumulators, and there is a loss in addition due to the additional weight of the accumulators to be drawn.

ELECTRICAL TERMS AND UNITS.

It may be useful to recapitulate these here :

Volt.—Unit of electro-motive force (E.M.F.) : *Electric Pressure.*

Ampere.—Unit of current; *rate* at which electric current is transmitted through the conductor forming the circuit.

Ohm.—Unit of electric resistance in the conductor. *Resistance* is that which tends to stop the flow of electricity.

Watt.—Unit to express rate at which electric power is absorbed or developed in an electric system, stated in terms of any two of the other units. It serves as a means of comparison between electrical and mechanical power.

Thus, to measure the power exerted by a current in a wire, the *volts* of electro-motive force and the *amperes* of *current* are measured. The two numbers are multiplied together. Or, the same result is obtained by multiplying the square of the current in *amperes* by the resistance in *ohms.* Products are the same, and give the rate of doing work, or the watts.

A Watt is $= \frac{1}{746}$th part of a horse-power.

Resistance of Conductors (say, a wire), is, 1st, proportional to its length; 2nd, is inversely proportional to the area of section; 3rd, depends on the material of which it is made.

	Conducting power.	Resistance.
Silver	100	·2421
Copper	99·55	·2106
Iron	16·81	1·2425
Lead	8·32	3·236
German silver	—	2·652

$$\frac{\text{Volts}}{\text{Ohms}} = \text{Amperes of current.} \qquad \frac{\text{Volts}}{\text{Amperes}} = \text{Ohms.}$$

The United States of America are conspicuously in advance of the United Kingdom in the application of electrical traction to tramways. In nearly every town in America, horse traction has been either totally or in part superseded by electrical traction. In the year 1892, the number of electrical tramways in the United States was 436, with 3,532 miles of track and 5,851 motor cars, travelling in the aggregate 50,000,000 miles and carrying 250,000,000 passengers annually. On the Continent, many important city tramway systems are now worked electrically. (For a list of electrical tramways in Europe, compiled by Mr. R. Hammond, see Appendix.) On the other hand, the British and Irish electrical tramways, aggregating 22 miles of way, have been reduced, during the past five years, by three on account of the abandonment of electrical working on those lines, whilst only six new lines have been added to the list, making 33¼ miles of way in all.

ELECTRICAL TRAMWAYS IN THE UNITED KINGDOM, 1893.

Year of opening.	——	Miles.	System.	——
1883	Portrush and Giant's Causeway	8	Side conductor . .	Water-power
1883	Brighton Beach .	1	Rails	Gas-engine
1885	Bessbrook and Newry Tramway .	3¼	Central conductor .	Water-power
1886	Ryde Pier . . .	½	Side conductor . .	Gas-engine
1886	Blackpool . . .	2	Conduit	Steam
1889	Carstairs	1¼	Side conductors .	Water-power
1890	Birmingham . . .	3	Accumulator . .	
1890	City and South London . . .	3⅙	Side conductor . .	Steam
1891	Southend Pier . .	¾	Central conductor .	,,
1891	Guernsey	2¾	Overhead conductor	,,
1891	Leeds	3¼	,, ,,	,,
1893	South Staffordshire	7½	,, ,,	,,
1893	Liverpool Overhead	6⅓	Central conductor .	,,

CHAPTER II.

EARLY ELECTRICAL TRAMWAYS.—BESSBROOK AND NEWRY TRAMWAY.

EARLY ELECTRICAL TRAMWAYS.

THE application of electrical transmission of power to railways was first exhibited by Dr. Werner Siemens, at the Berlin Exhibition of 1879. The current produced by a dynamo-machine, fixed at a convenient station and driven by a steam-engine or other motor, was conveyed to a dynamo placed upon the moving car, through a central rail supported upon insulating blocks of wood: the two working rails serving to convey the return current. The line was 900 yards in length, of 2 feet gauge, and the moving car served its purpose of carrying twenty visitors through the Exhibition each trip.

The success of this experiment led to the laying of the Lichterfelde line, in which both rails were placed upon insulating sleepers and served respectively for the conveyance of the current from the power station to the moving car, and for completing the return current.

This line, which is 2,500 yards in length on a gauge of 3½ feet, is worked by two dynamo-machines, developing an aggregate current of 9,000 watts, equal to 12 horse-power. The line has been in operation since May, 1881.

A line ½ kilometre in length, of 4 feet 8½ inches gauge, was laid at Paris in connection with the Electrical Exhibition of 1881.

Two suspended conductors, each in the form of a hollow tube with a longitudinal slit, were adopted, the contact being made by metal bolts drawn through the slit tubes, and connected with the dynamo-machine on the moving car by copper ropes passing through the roof. On this line 95,000 passengers were conveyed in the course of seven weeks.

An electrical line 765 yards long, 2 feet 2 inches in gauge, has been worked in connection with the Zaukerode Colliery since October, 1882.

An electrical tramway, 8 miles in length and 3 feet in gauge, was opened in 1883, connecting the town of Portrush with the Giant's Causeway, in the North of Ireland. It was designed by Dr. C. W. Siemens.

The rails are not insulated from the ground, but joined electrically by means of copper staples. The return circuit is thus formed, the current being conveyed to the car through a **T**-iron placed upon short standards about 3 feet high, and insulated by means of insulite caps. The power is produced by the utilisation of a waterfall near Bushmills by means of three turbines of 40 horse-power each and giving motion to a shunt-wound dynamo of 15,000 watts equal to 20 horse-power. The working speed is 10 miles per hour.

An electrical tramway half a mile long, and similar to the Portrush line, was laid on the Ryde Pier. It was constructed by Messrs. Siemens Brothers, and was opened in 1886 for electrical traction, converted from horse-power. The generating dynamo is driven by a gas-engine. The electrical working cost in December, 1886, was 6·3d. per mile run, against 8d. for horse traction.

BESSBROOK AND NEWRY TRAMWAY.*

A line of electrical tramway was constructed between Newry and Bessbrook (Co. Armagh, Ireland) for the carriage of coal and flax from the wharves to the mills, as well as the down traffic of manufactured goods, the abundant water power available offering exceptional advantages for the line being worked electrically.

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* The material for the notice of this undertaking has been

In the construction of the line the following conditions had to be met. Ten trains were to be run in each direction per day, providing for a daily traffic each way of 100 tons of minerals and goods, and capable of dealing with 200 tons in any single day, in addition to the passenger traffic :—the electrical locomotive to be capable of drawing a gross load of 18 tons on the up-journey, in addition to the tare of the car itself, and its full complement of passengers, at an average speed of 6 miles per hour, and a load of 12 tons at an average speed of 9 miles per hour.

The contract for the construction of the line was of a rather special character: the company agreed to place the line entirely at the disposal of Dr. Edward Hopkinson, to whom its construction had been entrusted, for a period of time, and to purchase the electrical plant at a fixed sum, when the above conditions had been complied with, and it had been shown that the cost of working as evidenced by six months' trial did not exceed the cost of steam traction on a similar line.

The work was commenced in November, 1884, and the line opened for traffic in October, 1885; it was formally taken over by the company, as having fulfilled the conditions of the contract, in the following April. Since that time it has been in regular daily operation.

The total length of the line is 3 miles 2·4 chains, the maximum gradient is 1 in 50, and the average gradient is 1 in 86. The gauge is 3 feet. For illustrations of the way, see page 392.

The locomotive equipment of the line consists of two passenger cars, 33 feet and 21 feet 8 inches long respectively, each provided with a motor. The body of the car is carried on two four-wheeled bogies, with a wheel-base of 4½ feet, the motor being carried on the front bogie independent of the body of the car (Fig. 341). By this

derived from Dr. Edward Hopkinson's paper on "Electrical Tramways," in the *Minutes of the Proceedings of the Institution of Civil Engineers*, vol. xci., 1887—88.

arrangement the cars are enabled to traverse the 55-feet curves at the termini with great facility, and also relieves the body of the car from the vibration due to the driving. The body of the longer car, Fig. 341, is divided into three compartments; the front one covers the motor; the second forms a second-class compartment, seating twenty-four passengers; and the third, a first-class compartment seating ten passengers, is separated from the second by a cross passage. The front bogie carrying the motor has an extended platform projecting 3 feet 7 inches beyond the body of the car, and communicating by a slide-door with the dynamo compartment, thus giving the driver direct access to all parts of the driving machinery, which are at the same time entirely boxed off from the passenger compartments. All four wheels are braked by a

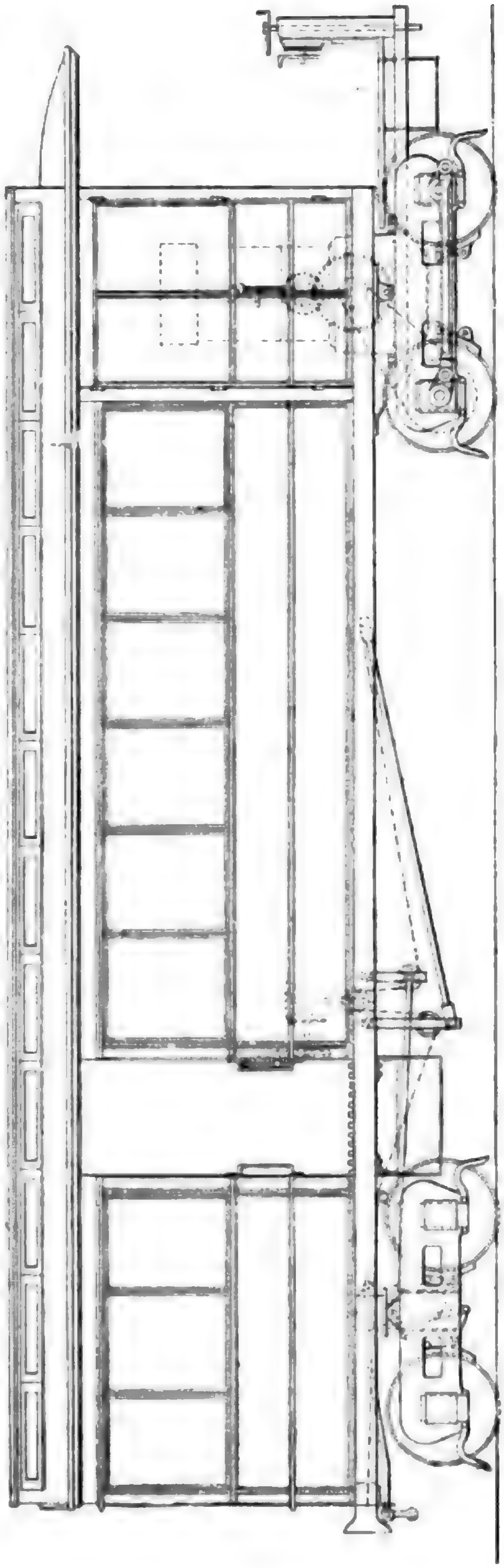

FIG. 341. Bessbrook and Newry Electrical Tramway: Passenger cars.

powerful screw-brake, worked from the front of the driving platform, on which is also fixed the switch-board controlling the motor. The wheels of the back bogie are braked by a chain brake, worked from the cross-passage, and are under the control of the conductor. This brake is also prepared for coupling to the wagons. The total weight of the car is 8¼ tons, distributed as follows :—

	Tons.	Cwt.	Qrs.
Car body	3	6	1
Leading bogie	1	17	2
Trailing ,, ...	1	0	0
Dynamo bed-plate, armature, and accessories	2	1	1
	8	5	0

The shorter locomotive-car is similar, but without the first-class compartments. There is also a third passenger-car of the same length as the first, accommodating forty-four passengers, and similarly carried on two four-wheeled bogies. This car weighs 5¼ tons. The wagons, having flangeless wheels, are, with the way, described and illustrated in pages 393 to 397.

The generating machinery is fixed at Millvale, a distance of 68 chains from the Bessbrook terminus. At this point, in close proximity to the line, there is an available fall of 28 feet in the Camlough stream, down which there is a guaranteed minimum flow of 3,000,000 gallons per day. The turbine is an inward flow vortex wheel with double buckets, working on a horizontal shaft extended into the dynamo shed, from which the dynamos are driven direct with belts. The capacity of the wheel is 1,504 cubic feet per minute, and when running at 290 revolutions per minute, should develop a maximum power of 62 H.P. It is worked with a tail draught of 13 feet. The admission of water is controlled by a shutter-valve, regulating the flow uniformly through each bucket of the wheel, and actuated either by hand or by a centrifugal governor. The latter is not direct-acting, but when its balls rise or fall beyond certain limits, it couples one of a pair of right and left-hand bevel-wheels, driven by a wheel on the governor spindle to a small countershaft geared with the valve-spindle.

There are two generating dynamos of the Edison-Hopkinson type, shunt-wound, for a normal output of 250 volts, 72 amperes, at a speed of 1,000 revolutions per minute. Three times that amount may be necessary for starting a heavy train on a steep gradient.

The resistance of the field magnets is 74 ohms, and that of the armature is 12 ohms. Consequently, the electrical efficiency with the normal current is 92·2 per cent., and the commercial efficiency 90·4 per cent.

The conductor is of channel-steel, laid midway between the rails, and carried on wooden insulators nailed to alternate sleepers. The electrical connection is made independently by a strip of soft copper of such section that its conductivity is about the same as that of the steel. It is bent in a U form to allow for the expansion and contraction of the channel. These strips are riveted in the channel with double copper rivets, care having been taken that the hole in the channel was perfectly free from rust before the riveting. At the several crossings of occupation roads, twelve in number, the electrical continuity of the conductor is broken by insulating a section of the channel, and the current is conveyed by a cable laid beneath the sleepers. The top of the channel being level with the rails, the intervening space can be paved or planked, thus making a good roadway without interfering with the mechanical continuity of the conductor. As none of these crossings exceed in width the length of the locomotive cars, the leading collector makes contact on one side the crossing before the back collector breaks on the other. The cables are of stranded copper wire, consisting of 37 No. 14 B.W.G.: 1st, cotton lapped and varnished; 2nd, heavily covered with pure rubber; 3rd and 4th, double served with best rubber separator; 5th, covered with pure rubber; 6th and 7th, taped with double-served proof tape, the cable then vulcanized and made water-tight; 8th, lapped with thick serving and tarred hemp; 9th, braided over all and heavily compounded. In constructing a conductor of iron or steel it is of the utmost importance to specify the composition. Steel may be obtained with a specific resistance varying from 0·00001 ohm to

0·00007 ohm, according to the amount of carbon, silicon, and particularly manganese. The steel used in this case was manufactured by the Darlington Steel and Iron Company, and specified not to exceed in carbon 0·15 per cent.; silicon, 0·05 per cent.; manganese, 1·00 per cent. The actual composition, according to the makers' analysis, is, carbon 0.09 per cent., silicon 0·02 per cent., manganese 0·63 per cent., and the specific resistance 0·0000121 ohm. The weight per foot of the conductor is 4·33 lbs. (6·46 kilograms per metre), and the section 1·367 square inch (8·817 square centimetres).

The insulators, which are of poplar wood, are 5 inches long. These are carefully dried and then impregnated with boiling paraffin. A block of dried poplar will absorb as much as 75 per cent. of its own weight of paraffin, which permeates through the whole mass. These blocks have proved efficient insulators, and they are apparently standing well. The actual measured insulation of the conductor, under unfavourable circumstances as regards weather and when charged to a potential of 250 volts, is about 900 to 1,000 ohms per mile, approximately the same as the insulation obtained at Portrush. Such an insulation is sufficient for practical purposes. It represents a loss, through leakage, of ¼ ampere, or one-tenth of a horse-power per mile. The actual measured leakage current of the whole line in wet weather amounts to nearly four times the above amount, the excess being probably due to some slight fault in the cables and arrangements at the points and crossings.

The circuit is completed by the rails of the permanent way, which are uninsulated. As is the case with the conductor, the fish-plate connections are not sufficient, and they are therefore supplemented by flexible copper strips riveted to the under surface of the rails. The specific resistance of the steel rails (Barrow Hematite) is 0·0000166 ohm, and hence the total resistance of the four rails, having an aggregate area of 12·4 square inches, is 0·033 ohm per mile. The resistance of the conductor is 0·221, making the resistance of the circuit 0·254 ohm per mile. Allowing for the earth and for some contact resistance, probably 0·25 ohm represents the average resistance per mile (0·156 ohm per kilometre). The electrical connection of the rails of the permanent way is essential, since the earth connection is of little value, as the rails are practically insulated by the sleepers and dry ballast.

Each locomotive-car is fitted with an Edison-Hopkinson dynamo-motor. As previously mentioned, the motor is fixed on the leading bogie, and is entirely independent of the body of the car. The armature shaft carries a double helical toothed steel pinion, 6·05 inches in diameter, gearing into a steel wheel 21·08 inches diameter, carried on a small countershaft running in bearings fixed on the bed of the motor. This shaft also carries a chain pinion-wheel of steel, 8·8 inches diameter, on the extended boss of which the helical toothed wheel is keyed. The chain pinion drives with chain gear on to a wheel 21 inches in diameter, keyed on to the back axle of the bogie, the wheels of which are 28 inches in diameter. This gives a ratio of gear of 8·3 to 1; hence a speed of 1 mile per hour corresponds to 100 revolutions per minute of the dynamo axle. To give the necessary adhesion the axles are coupled with outside connecting-rods.

The motors are series-wound with such a number of convolutions that the magnets are nearly saturated with 72 ampères, which is also the normal current for the armature. The resistance of the magnets is 0·113 ohm, and of the armature 0·112 ohm; hence if the potential between the terminals be 220 volts, the electrical efficiency with the normal current is 92·6 per cent., and the commercial efficiency 90·7 per cent., the power developed being nearly 20 H.P. In actual work the power of the motor frequently exceeds this amount. To transmit this power with the car running at, say, seven miles per hour, the tension of the chain would be 1,430 lbs., and the speed 460 feet per minute. At starting on a gradient with the full load the tension may reach 3,400 lbs., and with the car running at the maximum rate, the speed may reach 1,300 feet per minute.

A steel chain based on the well-known tricycle form was employed. The tubes are keyed as well as riveted in the inner links, and the pins in the outer links.

The current is conveyed from the conductor by two collectors fixed on the bogies. These form a good rubbing contact on the upper surface of the conductor. From them the current passes to the reversing and regulating switch fixed on the splash board of the leading bogie. To avoid throwing the full load suddenly on the generator and motor dynamos, a series of resistances are first thrown into circuit and cut out one by one. After passing through the armature and magnets, the current returns through the axle boxes and wheels to the rails.

The potential allowed by the Board of Trade is 300 volts, but the actual potential employed is only 250 volts.

The trains are commonly composed of one locomotive car and three or four trucks, but frequently a second passenger car is coupled, or the number of trucks increased to six. Thus a gross load of 30 tons is constantly drawn at a speed of 6 or 7 miles per hour on a gradient of 1 in 50.

The cost of the electrical equipment of the Bessbrook and Newry line is summarized as follows:—

	£	s.	d.
Turbine, pen-trough, and driving gear . .	330	0	0
Two generator dynamos, measuring instruments, and driving belts	450	0	0
Conductor at £200 per mile	600	0	0
Two locomotive cars, including their entire electrical equipment	1,120	0	0
	£2,500	0	0

The cost of each of the above items includes delivery and erection.

The cost of haulage was carefully ascertained over a period of five months, from November 21st, 1885, to April 22, 1886, and is given as follows:—

	£	s.	d.
Wages of driver and attendant at generator station	32	7	6
Sundry repairs	6	1	0
Oil, grease, and waste	5	4	10
Rental of water-power	59	16	0
Dynamo brushes, renewals of driving chain and commutators	14	11	6
	118	0	10

Train mileage, 8,652
Hence cost per train mile, 3·3d.

For the six months ending June 30th, 1887, during which period there had been a goods traffic of 8,000 tons over the line, a much larger amount than in the period referred to above, the cost per train-mile was something greater, as follows:—

	£	s.	d.
Wages	50	18	0
Sundry repairs and alterations, including the cost of changing the winding of four armatures of the dynamos	34	14	3
Oil, grease, and waste	10	0	0
Rental of water power	71	15	0
Dynamo brushes and sundry renewals	12	5	10
	£179	13	1

Train mileage, 10,276.
Hence cost per train mile, 4·2d.

The above amounts do not include anything for depreciation or for general supervision.

Subjoined are tables showing distribution of the power employed:—

DISTRIBUTION OF POWER.

	H.P. hours.	H.P. hours.	H.P. hours.
Total water power	30·4	20·63	13·9
,, electrical power developed by generator	18·1	10·86	4·71
Net power of motor	12·6	7·82	3·62
Loss in generator	1·68	0·88	0·40
,, in line resistance	1·82	0·65	0·14
,, leakage	0·71	0·52	0·39
,, motor	2·07	0·90	0·165
Sum of electrical losses	6·31	2·95	1·10

DISTRIBUTION OF POWER.

	First journey.	Second journey.	Third journey.
	Tns. Cts. Qrs.	Tns. Cts. Qrs.	Tns. Cts. Qrs.
Gross load	28 12 3	21 18 0	8 16 0
Mean speed in miles per hour	5·7	7·2	11·3
Total energy of water in foot lbs.	60,291,000	40,860,600	27,522,000
Total electrical energy developed by generator in foot lbs.	35,871,000	21,516,000	9,332,400
Net mechanical energy developed by motor in foot lbs.	24,928,200	15,493,500	7,170,900
Sum of electrical losses in foot lbs.	12,493,800	5,841,000	2,174,700
Loss in generator in foot lbs.	3,343,000	1,735,800	801,900
,, leakage ,,	1,420,300	1,029,600	775,500
,, resistance in line of foot lbs.	3,613,500	1,296,900	287,100
Loss in motor in foot lbs.	4,098,600	1,791,900	326,700
Total work done against gravity	11,867,400	7,356,800	2,858,300
Total work done against friction	13,060,800	8,136,700	4,312,600
Mean tractive force exclusive of gravity in lbs. per ton	28·9	27·4	37·1

PERCENTAGES.

	First journey.		Second journey.		Third journey.	
	Of the water power.	Of total power of generator.	Of the water power.	Of total power of generator.	Of the water power.	Of total power of generator.
Water power	100·0	—	100·0	—	100·0	—
Generator power	59·5	100·0	52·6	100·0	33·9	100·0
Net motor power	41·3	69·4	37·9	72·0	26·1	76·8
Loss in generator	5·5	9·3	4·2	8·0	2·9	8·6
,, leakage	2·3	3·9	2·5	4·8	2·8	8·3
,, line resistance	6·0	10·6	3·2	6·0	1·0	3·1
,, motor	6·8	11·4	4·4	8·3	1·2	3·5

The line has been regularly worked since October, 1885. The following table shows the traffic on the line in successive years:—

	Tonnage.	Mileage.	Passengers.
1886	12,238	19,872	97,636
1887	13,464	19,212	81,275
1888	14,928	20,376	85,450
1889	17,055	20,424	85,978
1890	16,173	20,478	92,447
1891	15,852	21,468	94,165
Total	89,710	121,830	536,951

The cost of haulage for the year 1891 was as follows:—

	£	s.	d.
Wages (drivers, guards, and dynamo engineer)	123	12	6
Maintenance and repairs of electrical machinery—materials	60	6	4
" " " wages	23	18	9
Oil, grease, and waste	9	6	2
Water rent	128	11	0
Total	£345	14	9

Train mileage, 23,468.
Hence cost per train mile, 3·94d.

CHAPTER III.

ELECTRICAL TRAMWAYS: BIRMINGHAM; BLACKPOOL; GUERNSEY.

BIRMINGHAM CENTRAL TRAMWAYS.—ELECTRICAL SECTION.

THE Bristol Road Section of the Birmingham system, three miles long, was opened in 1890. It is worked electrically on the accumulator principle. The ruling gradients are 1 in 28 and 1 in 32. The rails are of steel, girder section, 6 inches high, with a 7-inch flange base, fish-jointed, and weighing 92 lbs. per yard. They are laid on a 6-inch bed of concrete.

The cars, which resemble the double-bogie car already described (Plate III., page 372), are 6½ feet wide, 26½ feet long, to carry 24 inside and 26 outside passengers. The two bogie-trucks are about 15 feet apart between centres. The cells of the batteries are carried in trays underneath the seats—six trays on each side of the car, holding eight cells—96 in all.

BLACKPOOL ELECTRIC TRAMWAY.

The Blackpool tramway is 2 miles in length, and occupies the length of the Esplanade. During the season eight cars are constantly at work, seating on an average 45 passengers.

The electricity is generated at a central station, and is conveyed to the cars by means of an underground channel or "tube" in the centre of the track, having a narrow slit or opening for communication between the electric motor on the car and electric conductors within the channel. The channel is formed strong enough to support the ordinary traffic of the road, and so as to be easily flushed and cleansed. Its surface consists of steel troughing filled with wooden paving blocks, and forms a good roadway. The sides of the channel are partially formed of creosoted wood, holding porcelain insulators which carry electric conductors of special drawn copper so formed that they can be readily and securely fixed, and the lengths secured by expansion joints.

Two conductors are supplied, first, that they may be hidden in the tube under either side, and so be protected from injury by any substance falling through the slit channel; and, secondly, to make it possible to deal with points, loops, and crossings. Only the positive electricity passes along these conductors; the return is made by means of the rails, which are electrically connected one with the other.

Communication is made with the cars by means of a collector which runs upon the copper conductors within the channel. Insulated copper bands, protected by steel plates, pass through the slit or opening in the surface of the road, and by a flexible insulated cord attached to an electrical terminal underneath the car, so that when the car moves the collector is drawn along with sufficient force to clear away any ordinary obstruction. But should an absolute block occur, then a special clip releases the collector, and a breakage is avoided.

From the terminal underneath the car the current passes to the switch-box, where the quantity and direction of the electricity to and within the motor is regulated, and thereby the speed and direction of the car is controlled.

Switch-boxes are placed at each end of the car, and are provided with removable handles, without which it is impossible to operate them. The driver, who has charge of these handles, can cause the car to move backwards or forwards at will. From the switches the current goes to the motor and there produces mechanical energy. The motor runs at a high speed, and a combination of spur and chain gear is employed to communicate the power to the wheels and drive the car. The gear is specially designed to run smoothly and silently. From the motor the current passes by way of adjustable clips to the axles, and by them through the wheels to the rails and back to the station where the electricity is generated.

The engines and dynamos are in duplicate, and so made that they produce just the amount of electric energy required, so that, if no car be running, no work is expended; if one car runs, just enough energy to drive one, and no more; if ten cars, sufficient for them, and so on up to the full capacity of the machines, which are constructed to the requirements of the line.

The generators fixed at the engine-shed are capable of driving ten loaded cars—sufficient to carry 400 passengers.

The capacity for carrying exceptional traffic with a very small increase in the working expenses is exemplified as follows:—

The number of passengers carried during a week of six days in the winter was 2,393 at a cost, for fuel and wages, under £24. During the week ending September 4th, 1886, which was in the height of the season, the number of passengers carried was 44,306, while the cost of wages and fuel was only £45

GUERNSEY ELECTRIC TRAMWAY.

This line of tramway consists of three miles of single way with turnouts, following the coast line between St. Peter's Port and St. Sampson's. It was originally worked by steam locomotive power, but this service proved to be irregular and unsatisfactory—working over constantly recurring curves and inclines, and stopping to suit passengers—and it was superseded about two years ago (1892) by electric power, with overhead conductors, for which the entire equipment was supplied by Siemens Brothers & Co.

The generating plant consists of two compound steam-engines, each of 25 nominal horse-power, and two locomotive boilers. Each engine is fitted with a Worthington pump, a Friedman injector, and a feedwater heater. The first cylinder of each engine is 10 inches, and the second cylinder 16 inches, in diameter, with a common stroke of 18 inches, making 120 turns per minute. The flywheel is 8 feet in diameter, and weighs 42¾ cwt. The working pressure is 140 lbs. per square inch. The first cylinders are fitted with Hartnell's expansion gear. With this gear the speed is nearly constant: within 5 per cent.

A Siemens compound-wound central station dynamo, capable of giving 100 amperes at a pressure of 500 volts, is belt-driven by each engine, at a speed of 350 revolutions per minute. A Schaffer and Budenberg tacheometer can be connected at will to either dynamo. A single engine and dynamo suffice for ordinary traffic. The sets work alternate fortnights. The average daily run is 17½ hours without stop. An ingenious arrangement of switchboard permits the reserve dynamo to be thrown in at any time, and the load to be halved between the two machines, without interruption of running.

The station buildings are of stone and corrugated iron, the power-house, workshop, car, and coal-shed being conveniently connected together. Three tracks run into the car-shed, and each has a pit 46 inches by 54 inches for its entire length, affording easy access to the driving mechanism and running gear. All repairs are made at the station. A separate plant is to be put in for lighting the buildings electrically.

The working stock consists of seven motor cars and two trailers. Four of the motor cars have bogie trucks and double motors in series, and they seat 68 persons each. The three others have ordinary 4-wheel gear and single motors, seating 52 each. Each motor is of 7 nominal horse-power. With the exception of the motors employed on the two bogie cars last built, the motors are of the Siemens double magnetic circuit type, and are furnished with single reduction gearing. The pinion is of phosphor bronze, and the split wheel on the car axle of cast-steel. The motor casing is of wood, metal lined. The two newest cars have a simple magnetic field type of motor, and chains have been abandoned in favour of single reduction spur gear. The pinion in this case is cut out of a single block of steel, and carefully polished, the spur-wheel being cast in halves and bolted together on the car axle. This gear runs much more quietly and with less wear and tear than the chain gearing. Armature and gearing are enclosed in a cast brass casing, which serves as an oil bath for the gear, and protects the armature from dust and wet. All armatures are of the drum type. The speed is regulated by the introduction of artificial resistances of iron wire, carried beneath the car flooring. The motors are supported on rubber cushions. The brushes are of copper gauze, and a set lasts from three to four weeks.

Connection between the overhead conductor and the car is made in the ordinary way by a trolley pole and wheel. The only peculiarity is that the trolley head is connected to the hollow steel pole by means of a piece of ash, being thus insulated from the pole and its base. The insulated cable, carrying the current to the motors, passes through the tubular pole. The trolley itself pivots on a socket-head furnished with ball bearings, and the upright supporting these bearings is screwed into a cast-iron bracket bolted to the side and top of the car. The usual upward pressure of the trolley against the wire is about 26 lbs.

The trolley wire along the line is supported about 2 feet outside the track by light bracket arm poles. The position of these poles having been fixed by the "States" of Guernsey to correspond with those formerly occupied by lamp-posts, the brackets are of varying lengths. At curves, "pull-off" poles and cross suspension wires are employed. According to length of span and strain, three different sizes of poles are used. All are of the Siemens telegraph style, consisting of a cast-iron base, into which is fixed a tubular, conical wrought-iron pole. The trolley wire itself is of 9-millimetre hard-drawn copper. The spans vary between 40 and 48 yards. The whole overhead construction is very light and inconspicuous.

The permanent way is very old, and is about (March, 1894) to be replaced. The metals are partly Vignoles and partly old-style grooved tramway rail. Where tram rails are used, the return circuit is secured by means of lengths of 4-millimetre copper wire, fixed to the metals by channel pins, and attached to a bare copper return wire, 9 millimetres in diameter, laid between the rails. The Vignoles rails are connected by means of an iron strip riveted to the bottom flange of each rail, and electrically welded to it. With these rails no return wire is used. The weight of rail is uniformly 41¼ lbs. per yard.

For the three months ending December 31, 1893, the following information is given:—

Average number of cars running	5
" daily mileage per car	70
" speed per hour in miles	7·2
" pounds of coal consumed per car-mile	8
" number of passengers per car-mile	7
" " " " holidays	13

Costs per car-mile.	d.
Salaries	0·652
Wages and repairs in power-house	0·636
Wages of drivers and conductors	1·716
Workshop repairs and car-cleaning	1·243
Maintenance of permanent way and electrical conductors	0·312
Coal	0·747
Oil and sundries in power-house	0·234
" " repair shop and car-shed	0·181
Printing and stationery	0.070
Total per car-mile	5.791

Coal and other stores are expensive on account of freights. The cost of running, strictly speaking, viz.—coal, oil, waste, &c., wages of engine and car drivers, conductors, car cleaners, and everything directly connected with car service—does not exceed 4d. per car-mile.

A four-mile extension of the road to Cobo, and a branch line to Bordeaux Harbour, are now contemplated. Large granite quarries are situated at these points, and it is proposed to run a regular freight service, as well as passenger cars, to bring the stone from quarry to ship by the electric line.*

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* The matter of this notice is derived from a paper by Mr. Philip Dawson, C.E., in *Engineering* of March 30, 1894.

CHAPTER IV.

CITY AND SOUTH LONDON RAILWAY.[*]

THIS railway, worked by electricity, was opened for public traffic in December, 1891. The line consists of two independent tunnels formed of cast-iron rings. The sleepers are transverse, resting directly upon these rings, and the rails are spiked thereto, and leave a minimum headway of 9 feet from the rail-level to the highest point of the tunnel. Fig. 342 shows a section of the tunnel and the space available. Where the line passes under the Thames, between Great Dover Street and King William Street, there is on the up line a down-gradient of 1 in 30 for a distance of 264 feet, and an up-gradient of 1 in 30 for 462 feet; and on the down line a down-gradient, with the traffic, of 1 in 14, followed by an up-gradient of 1 in 30. At other points of the line the gradients are not severe, the principal being an up-gradient of 1 in 100 approaching Stockwell Station. The total length of the line is 3 miles 270 yards. There are four intermediate stations.

The generator station is situated at Stockwell, at a distance of about 500 feet from that terminus. There are eight boilers of Lancashire type, each 28 feet long and 7 feet in diameter, fitted with Vicars' automatic stokers. The boiler-floor is 12 feet 6 inches below the ground level (Fig. 343), and the boiler-house is roofed over, except immediately above the stokehole, so as to provide room for a fuel store. By this arrangement the fuel can be shovelled direct into the hoppers of the stokers. The pressure at the boilers is 140 lbs. per square inch. In addition to providing steam for the electric-generating engines, the boilers are required for producing steam for the powerful hydraulic plant, and the auxiliary engines of the repairing shop, the compressed-air pumps, and the hauling engine for drawing the locomotives and carriages up the inclined way connecting the Stockwell Terminus with the depôt. The boilers are set on Livet's principle of expanding flues, and are arranged in two groups of four, with independent flues and chimneys. The steam-pipes from the two groups are arranged so that either or both can be connected to the main

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[*] The materials for this and the succeeding notices have been derived from Dr. Edward Hopkinson's paper on "Electrical Railways," in vol. cxii., and Mr. Sheibner's paper on the "Florence and Fiesole Electric Railway," in vol. cvi., of the *Minutes of Proceedings of the Institution of Civil Engineers.*

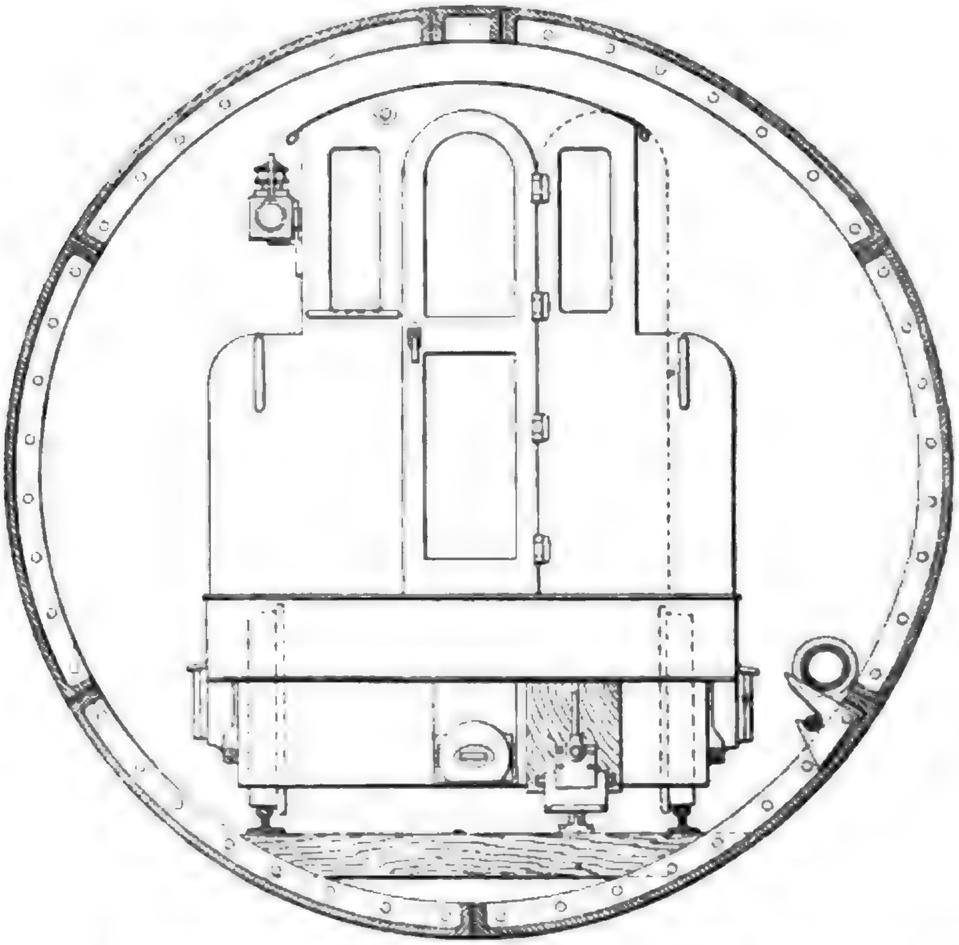

FIG. 342. City and South London Railway: Transverse Section of Tunnel.

pipes crossing beneath the yard to the engine-house, otherwise there is no duplication of the steam-pipe system. The exhaust steam from all the engines passes by a single pipe through the water heaters to the chimney. As there is no water available for condensing purposes, all the engines are non-condensing; steam power, therefore, is not produced under the most economical conditions.

There were originally three engines, each of them driving one generating dynamo; but the Company has since added a fourth similar engine and dynamo in view of the extension of the line to Clapham, and to meet the requirements of the Board of Trade as to reserve power. The engines are of the vertical compound open type; the cylinders are side by side, 17 inches and 27 inches in diameter respectively, and 27 inches stroke. The fly-wheels are 14 feet in diameter and carried between the cranks, which are of disc form. Both cylinders are steam-jacketed in the barrels, with high-pressure steam, and are fitted with slide-valves, with cut-off valves on both cylinders, controlled by the governors. The engines run at one hundred revolutions per minute. They are each capable of indicating 400 H.P., and drive the dynamos with link-leather belts, which are provided with jockey pulleys to allow of the distance between the engine and the dynamo centres being reduced without unduly diminishing the area of contact on the driven pulleys.

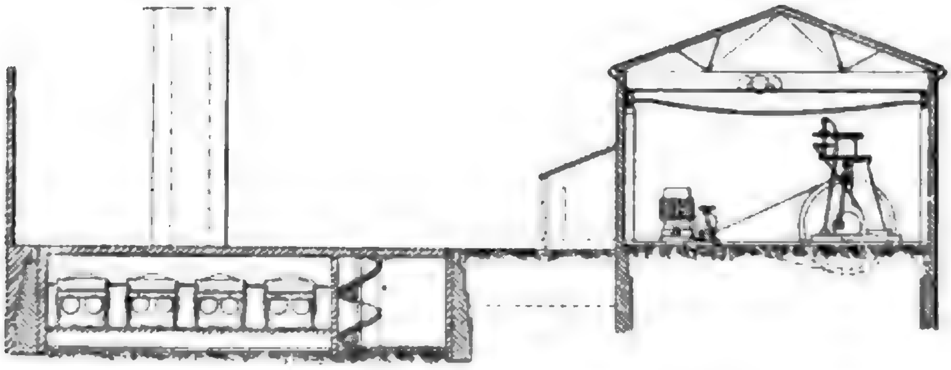

FIG. 343.—City and South London Railway: Boiler-house and Engine-house at Generator Station.

The generating dynamos are of the Edison-Hopkinson type with bar armatures 19⅜ inches in diameter. The field-magnet coils are wound with both shunt and series coils, but the latter can be half short-circuited, or entirely so, at will, by means of switches fixed on the dynamo. Each dynamo is capable of giving an output of 450 amperes at 500 volts, running at a speed of 500 revolutions per minute. The following are the electrical constants of the machines: Resistance of armature, 0·017 ohms; of shunt coils, 96·0 ohms; of series coils, 0·015 ohms.

The electrical efficiency at full speed is 96 per cent., and the weight of the armature is 37 cwt. The weight of the entire machine is 17 tons.

Careful independent experiments were made upon the efficiency of conversion, which showed that the frictional losses amounted to 2·7 per cent. of the full load. Hence the commercial full-load efficiency is 93·4 per cent.

The switch-board is arranged so that any of the four generators can be coupled to any of the four feeders, either independently or in parallel, and that any fresh combination can be instantly effected without interruption of the working. The electromotive force of each dynamo is measured by a Kelvin electrostatic multicellular voltmeter, and the current passing through each feeder is measured by an ampere-meter. The leakage of any part of the entire system of conductors, when subjected to the full potential, can be measured by a special low range ampere-meter. The feeders are provided with fusible cut-outs and quick-acting safety switches, which automatically throw a resistance into circuit if the current exceeds a certain amount; the object being to prevent injury if an accidental short circuit should take place on any part of the system.

From the switch-board there are four feeders, two of which are connected to the working conductors at Great Dover Street station, a distance of 12,800 feet from the generating station. The other two are coupled in parallel as far as Stockwell, and one is continued to the Oval, where it is connected to the working conductors at a distance of 4,330 feet from the generator station.

The cables, which were manufactured by the Fowler-Waring Company, consist of a standard core of 61—14 B.W.G., insulated and sheathed with lead, and have an insulation resistance of not less than 500 megohms per mile. They are carried along the tunnels supported on the brackets carrying the hydraulic pipes.

The working conductor is similar to that adopted for the Bessbrook and Newry Tramway, and consists of channel steel laid between the rails, and carried on glass insulators fixed to alternate sleepers. The channel weighs 10 lbs. per lineal yard, and was rolled from mild ductile steel of special composition. The suitable proportions of carbon, silicon, and manganese for steel conductors have already been discussed. By eliminating the silicon and slightly diminishing the carbon, a steel was obtained having a specific resistance as low as 0·0000105 ohm at 24° Centigrade, although the amount of manganese allowed was somewhat increased. This corresponds to a resistance of 0·0503 ohm per 1,000 feet.

It will be observed that the level of the conductor is 1 inch below that of the rail-level. This, of course, necessitates arrangements for the lifting of the collectors over the crossing-rail at points. The conductor is broken on either side the crossing-rail, and replaced by inclined planes of wood, up which the collectors slide till raised to a level of 1 inch above the crossing-rail, which passes through a gap left in the wooden runners. The collectors cross the gap at an angle, and are wide enough to bridge it. As each locomotive is provided with three collectors, the continuity of the circuit is never broken, as the leading collector makes contact with the steel conductor in advance of the break before the trailing collector leaves the conductor behind the break. The conductor is also divided into sections, and arranged so that any section can be coupled through automatic cut-outs to the adjacent sections, or independently to the feeders. Thus any section can be isolated for the purpose of testing or repairs, and is automatically disconnected in case of any accident causing a short circuit to earth. The return circuit is through the rails, which are practically uninsulated. In such a system high insulation from the earth is neither aimed at nor required, provided the power lost in leakage is inconsiderable. The actual leakage on the entire system, consisting of dynamos, feeders, and working conductors, tested at 500 volts pressure, is generally about ½ ampere, corresponding with a loss of 0·3 H.P., and it rarely exceeds one ampere under the most unfavourable atmospheric conditions.

The essential feature in the design of the locomotives, Figs. 344 and 345, is, that the armatures of the motors are built directly upon the axles, while the magnets are supported partly on the axle and partly on the frame. Thus gearing is entirely obviated, and the mechanism is reduced to the simplest elements. Although this principle of direct driving was suggested many years ago by the late Sir William Siemens, it has not previously been applied in practice. The field-magnets embrace the armature, leaving but an exceedingly narrow "gap," and are supported in part by brackets parallel to the axle with bearings upon it, and partly by links connecting the yoke to a cross-beam of the locomotive frame, thus permitting limited freedom

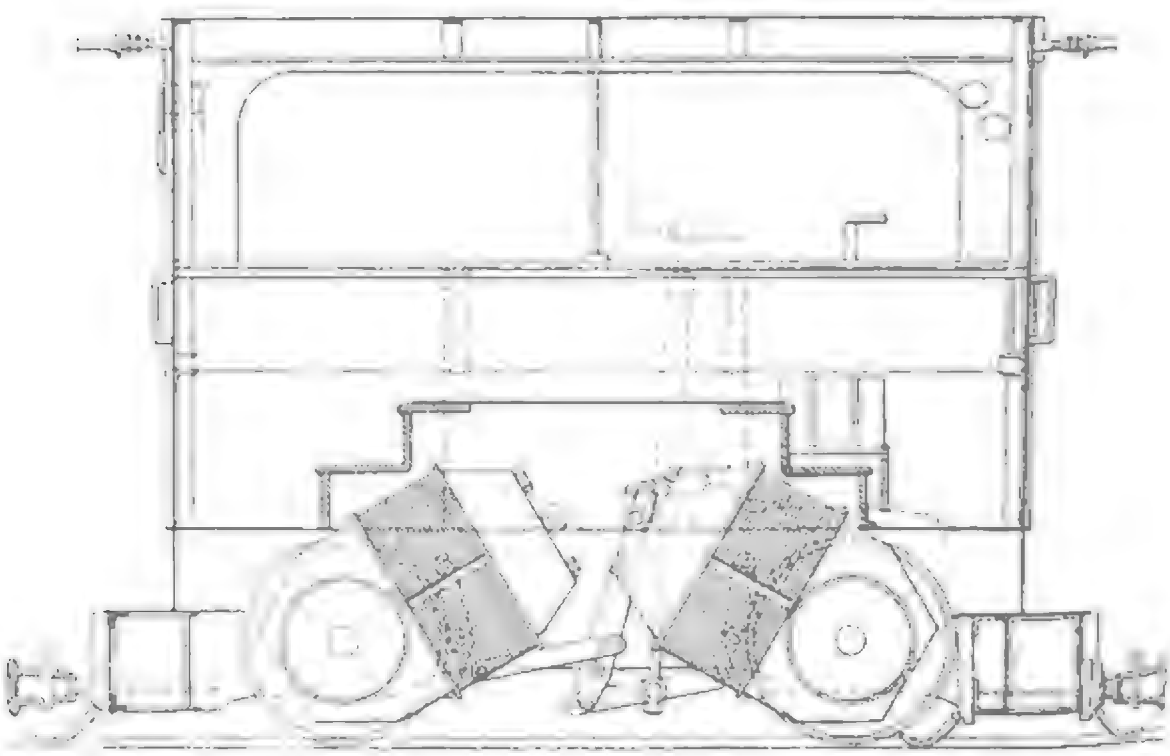

Fig. 344.—City and South London Railway: Locomotive. Showing Motors.

of angular motion of the field round the axle, and compensating for the rise and fall of the axle-boxes in the horn-blocks. The weight of one axle with its wheel, axle-boxes, and springs, and with the armature attached, is 24 cwts., and the part of the weight of the magnets resting on the axle is 10 cwts., whence the total dead weight on each axle is 34 cwts.

The two motors on each locomotive on the South London line are each capable of developing 50 H.P. at a speed of 25 miles per hour, corresponding to 310 revolutions of the axle per minute. The magnets are of the "Edison-Hopkinson" form and series-wound; and the armatures are of the Gramme-ring type. The resistance of the magnet coils of each motor is 0·087 ohm, and of the armature 0·3 ohm. The two motors are connected electrically in series. The current from the conductor is conveyed from sliding collectors through a fusible cut-out and main switch to

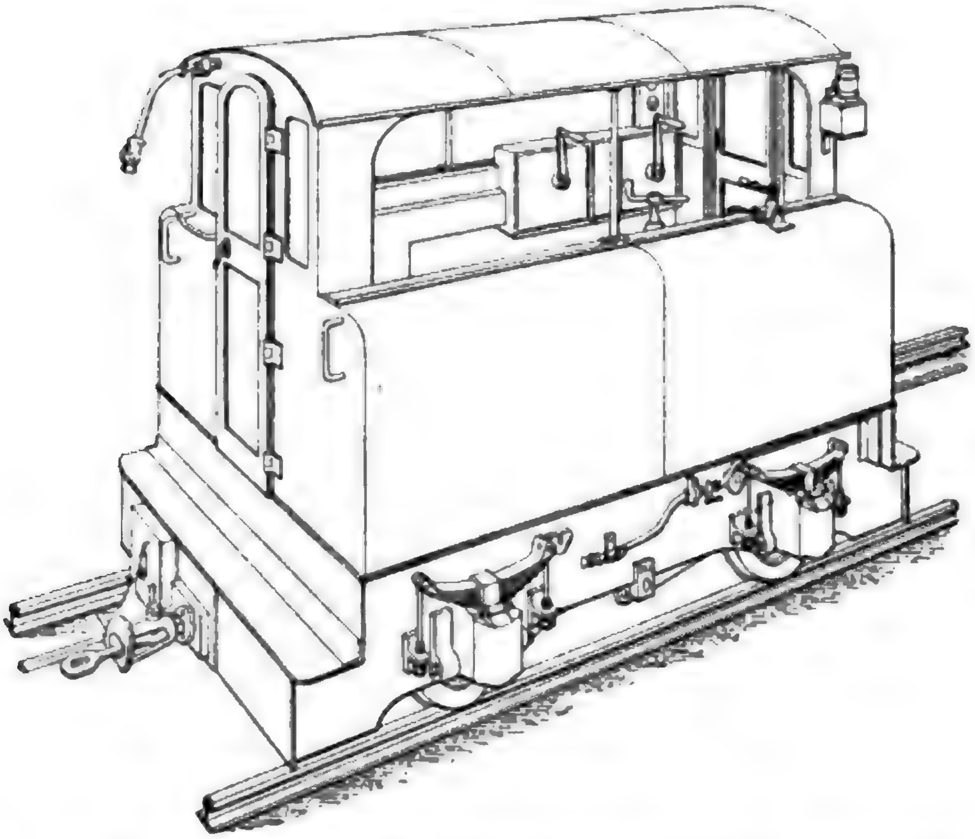

FIG. 345. City and South London Railway: Locomotive. Perspective view.

a rheostat switch for inserting resistance at starting; thence it passes through a reversing switch to the motors, and finally through the axle-boxes and wheels to the rails of the permanent-way. The motor-magnets are proportioned relatively to the armature, precisely as in a dynamo, and are wound so as to be nearly saturated with the mean working current. Above this point the curve of tractive force and current is approximately a straight line, giving a tractive force of 1,180 lbs. with 100 amperes, and a maximum of 3,000 lbs. with 226 amperes. The trains are fitted with the Westinghouse continuous automatic brake, applied, however, in a novel manner suggested by Mr. Greathead. In place of a pump working continuously on the locomotive, the latter is provided with two reservoirs placed under the curved side-plates of the cab, each of about 8·25 cubic feet capacity. At the end of each double journey these are charged with air at 80 lbs. pressure, from a small reservoir erected at Stockwell, the pressure in which is maintained by two small pumps in the engine-house. The reservoirs on the locomotives are of sufficient capacity to provide for about thirty stops from full speed. This system has proved both convenient in practice and economical, the total amount of steam required for the brakes being about 1·5 per cent. of the entire consumption. In addition to the Westinghouse brake, a powerful hand-screw brake is fitted on each locomotive. The locomotives and carriages are lighted with glow-lamps supplied direct from the conductor, an arrangement which has the merits of simplicity and cheapness, but is open to the objection that the light is necessarily subject to some fluctuation, owing to the variations of the electromotive force of the conductor.

The following are the leading dimensions of the locomotives:—

	Ft.	Ins.
Length over central buffers	14	0
,, ,, cab ,,	10	0
Wheel base	6	0
Diameter of wheels	2	3

	Ft.	Ins.
Gauge	4	8½
Extreme width of cab	6	3
Height, rail level to floor plate	2	5¼
,, floor plate to roof	6	0

Weight of entire locomotive, 10 tons 7 cwt.
,, ,, motors only, with wheels and axles, 6 tons.

Of the fourteen locomotives first supplied thirteen are of the direct-acting type, and one is a geared locomotive. Since the opening of the line two additional locomotives have been furnished by Messrs. Siemens Brothers. In these the general feature of the design described have been followed, but the armatures are of "drum" in place of Gramme type.

The efficiency of the system is considered in three stages:—the production of electric power; the distribution of electric power; and the reconversion of electrical into mechanical power.

(1.) The daily consumption of water for all power purposes is about 330,000 pounds, evaporated by 21 tons of North-country slack, or 7 pounds per pound of fuel. From 60 to 67 per cent. of the total steam produced is absorbed by the electric generating engines, consuming about 14 tons of coal per day. The average "load" on each engine is approximately "230 horse-power," represented by 27·5 pounds of water per H.P. per hour.

The efficiency of the engines and dynamos combined was ascertained by indicating the engines and measuring the electrical output at the terminals of the dynamos, when working on a steady load. These experiments show an average efficiency of available electrical H.P. against indicated H.P. of—at full load, 78 per cent.; at three-quarters load, 70 per cent.; at half-load, 65 per cent.

The daily consumption of electrical energy is about 3,700 Board of Trade units, which are produced from the combustion of 1[illegible] tons of coal, or 8·[illegible] lbs. of North-country coal per Board of Trade unit, corresp[illegible] to about 7·5 lbs. of Welsh coal per unit. urren

(2.) The efficiency of distribution is not of general interest, as it depends solely upon the resistance of the conductors. It is sufficient to state that the average full load loss in the long feeders running to Great Dover Street is 5·7 per cent., and in the short feeders 3·5 per cent. Thus the total loss in the feeders is 9·2 per cent. The distant feeders are usually coupled to a generator-dynamo working full-compound, while the home feeders are connected to a generator working half-compound, and thus compensating for the loss of electromotive force in the feeders. The loss in the working conductors can only be estimated from the average current in each section and the known resistance. It probably does not exceed one per cent., making the total loss in distribution a little more than 10 per cent. of the total electrical power generated. This represents a daily expenditure of fuel of about 1½ tons of North-country coal, which is almost the exact equivalent of the interest on £7,000, the actual cost of the conductors. Thus the continuing cost of distribution is a minimum.

(3.) The results of observations made with train-loads of from 35 tons to 40 tons show the electrical efficiency of the entire system to be about 62 per cent. The loss in the conductors being a little over 10 per cent., the average electrical efficiency of the locomotives is 70 per cent. The 30 per cent. of loss includes the power absorbed in the starting resistance—probably one-half. The average speed of working, including intermediate stoppages, is 11·5 miles per hour, and of actual running between stations 13·5 per hour. The maximum speed attained between stations varies from 20 to 25 miles per hour. The weight of a normally loaded train is 40 tons. The daily mileage for the half-year ending June 30, 1892, was 1,120; hence the consumption of fuel per train-mile is 28 lbs. of North-country coal, equivalent to about 25 lbs. of Welsh coal. This result compares very favourably with the best results of American tramway practice, having regard to relative loads and speeds.

The working expenses for the four half-years, 1891—1892, are given in the following table:—

COST OF LOCOMOTIVE AND GENERATING POWER, CITY AND SOUTH LONDON RAILWAY, 1891—1892.

	Half-year ending											
	June 30, 1891.			Dec. 31, 1891.			June 30, 1892.			Dec. 31, 1892.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Salaries, office expenses, and superintendence	65	12	0	100	8	4	192	3	4	148	11	8
RUNNING EXPENSES.												
Wages connected with working the generating and locomotive engines	3,408	16	10	3,258	1	9	2,720	8	1	2,788	12	6
Fuel	2,054	4	10	1,985	18	6	1,970	19	4	2,172	0	9
Water and gas	251	5	6	263	9	6	253	11	0	252	9	9
Oil and stores	434	2	1	371	18	1	415	3	4	457	6	11
REPAIRS AND RENEWALS.												
Wages	150	0	0	26	3	9	205	0	0	240	0	0
Material	223	2	1	193	13	0	277	17	10	289	3	1
Total	6,587	3	4	6,199	12	11	6,035	2	11	6,348	4	8
Total of running expenses only	6,148	9	3	5,879	7	10	5,360	1	9	5,670	9	11
Train mileage	174,435			188,666			188,944			214,417		
Total cost of locomotive and generating power per train mile	9·1d.			7·8d.			7·7d.			7·1d.		
Running expenses per train mile	8·4d.			7·0d.			6·7d.			6·3d.		

For the last half-year, the total working cost is 7·1d. per train mile. During the two years since the opening of the line in December, 1890, the locomotives ran more than 820,000 miles, having carried over 12,000,000 passengers. The yearly mileage run per locomotive in regular running exceeds 30,000 miles.

The costs of working the generator station and the locomotives, excluding office expenses, are given below separately: the cost of production of electricity, and the cost of locomotive power, or of utilising the electric current and reconverting it into mechanical power. The total cost of the generating power is 4·59d. per train mile, and that of the locomotive power is 2·31d. per train mile.

CITY AND SOUTH LONDON RAILWAY: LOCOMOTIVE AND GENERATING POWER SEPARATELY.

HALF-YEAR ENDING DECEMBER 31, 1892.

Train mileage	214,417
Number of passengers	3,317,602

COST OF WORKING GENERATOR STATION EXCLUDING OFFICE EXPENSES.

	£	d.		
Wages	1,012	1·12	per train	mile.
Fuel	2,172	2·42	,,	,,
Water and gas	252	0·28	,,	,,
Oil and stores	368	0·41	,,	,,
Repairs and renewals . . .	321	0·36	,,	,,
	4,125	4·59	,,	,,

Equivalent to 1·56d. per Board of Trade unit.

COST OF LOCOMOTIVE WORKING EXCLUDING OFFICE EXPENSES.

	£	d.		
Wages	1,776	1·98	per train	mile.
Oil and stores	89	0·10	,,	,,
Repairs and renewals . . .	208	0·23	,,	,,
	2,073	2·31	,,	,,
Total	£6,198	6·90	,,	,,

Since the foregoing results were produced the statements of accounts for the half-year ending June 30, 1893, have been published. The revenue expenditure was as follows :—

REVENUE EXPENDITURE FOR HALF-YEAR ENDING JUNE 30, 1893.

	£	s.	d.
Maintenance of Way, Works, and Stations	452	13	1
Locomotive and Generating Power	5,876	1	10
Carriage repairs	480	7	3
Traffic expenses	5,799	16	0
General charges	1,710	0	5
Passenger duty	24	1	2
Law charges	50	0	0
Rates and taxes	554	2	3
Compensations	16	18	6
Expenditure	£14,964	0	6

Train miles run	217,661 miles.
Number of passengers	3,146,656
,, season tickets	299

	£	s.	d.	£	s.	d.
Receipts	21,748	12	6			
,, season tickets	709	14	3			
				22,458	6	9
,, parcels, &c.				18	19	8
Total (24·8d. per train mile)				22,477	6	5
Expenditure (16·5d. ,,)				14,964	0	6

The locomotive and generating power together amount to £5,876 1s. 10d., or 6·5d. per train mile, against 7·1d. for the preceding half-year, ending December 31, 1892, already noted.

CHAPTER V.

CONTINENTAL ELECTRICAL RAILWAYS.—FLORENCE AND FIESOLE RAILWAY.

SIX CONTINENTAL ELECTRICAL RAILWAYS.

MR. SHEIBNER gives the subjoined table, based on official documents, for the purpose of comparison. It comprises the leading features, working cost, and performance of six electric railways on the continent. On the old Lichterfelde line, the first in the table, the circuit is formed simply by the rails. On the next four lines, both the conducting and contact wires are placed overhead, but laterally to the line, the current being transmitted to the cars by a small trolley running in a slot along the contact wire; whereas the Florence line has the simpler arrangement of a central overhead contact wire and trolley-pole.

The Pesth lines are the only lines constructed on the underground channel-and-slot system, which is of necessity very costly in construction; so much so that, for sake of economy, an extension of the lines has been made with overhead wires. On the Mödling line, power is generated by a locomotive engine of 140 horse-power, in addition to three small stationary engines of 15 horse-power each. On the Montreux line, local water-power owned by the company is utilised, the dynamos being driven by two turbines of 120 horse-power each. The average cost of construction of these two lines and the Florence line was £4,200 per mile; the average working expenditure is 45 centimes per train-kilometre, or 7d. per train-mile. The three lines Mr. Sheibner takes as typical examples of economy, efficiency, and success.

LEADING FEATURES, WORKING COST, AND PERFORMANCE OF SIX CONTINENTAL ELECTRIC RAILWAYS, 1881—90.

Opened in	Name of line.	Length of line.	Gauge.	Maximum gradient.	Minimum radius of curves.	Total horse-power.	Cost of line per kilometre.	Cost of line per mile.	Kilometres run per day.	Working expenses per train-kilometre run.	Working expenses per train-mile.	System.
		Kilometres.	Metres	Per cent.	Metres	H.P.	Francs.	£	Kilometres.	Centimes	Pence.	
1881	Berlin and Lichterfelde	2·5	1·00	1·1	30	..	..	..	..	75 (2 cars)	11·49	Siemens and Halske
1888	Ditto Extension	1·4	1·00	1·1	30	..	..	..	..			
1883—5	Mödling (Vienna)	4·4	1·00	1·6	30	185	40,000	2,552	214	47·0	7·20	„
1884	Frankfort & Offenbach	6·7	1·00	3·0	30	230	147,000	9,378	1,400	58 (2 cars)	8·89	„
1889	Vevey and Montreux	10·4	1·45	4·5	40	240	65,000	4,147	1,013	40	6·13	Vevey and Montreux Electric Works Co.
1890	Buda-Pesth	9·1	1·45	1·6	25	500	..	..	1,085	..	..	Siemens and Halske
1890	Florence and Fiesole	7·3	1·45	8·0	18	240	96,000	6,125	600	49·5	7·58	Sprague

THE FLORENCE AND FIESOLE ELECTRICAL RAILWAY.

This line is 7·3 kilometres, or 4½ miles, long, having gradients up to 1 in 12½; and is the first continuous steep-grade electric railway in Europe. It is worked on the overhead system of conductors. The line was opened throughout in April, 1891. Of the total length, 52 per cent. is in curves, down to 59 feet radius, and is chiefly on the steep-grade section. The electric works are situated at St. Gervasio, about 1½ miles from Florence.

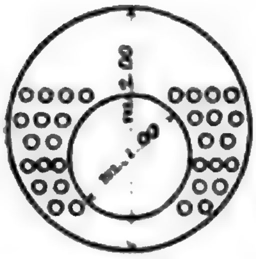

FIG. 347. Fiesole Railway: Section of Boiler.

The general arrangement of the station, with engines, dynamos, &c., is shown in Fig. 346 (Plate VII.). Steam is supplied from three return-flue boilers, Fig. 347, 6·56 feet in diameter, with an inside flue 1 metre in diameter, to work three vertical compound engines of 80 horse-power each, making 225 revolutions per minute, and driving three Edison compound dynamos, Fig. 348 (Plate VII.), which, at 900 turns per minute, give 110 amperes at 500 volts, each dynamo developing 75 effective horse-power, or 93 per cent. of the engine-power. There are, at least, one engine and one dynamo always kept in reserve. Cardiff coal is consumed at the rate of about 1,980 pounds per engine per day, making steam of 140 lbs. per sq. in. The feed-water is heated up to 176° F. before use.

An overhead main conductor, consisting of a covered copper wire, No. 3, B.W.G., is carried on poles placed at a distance of from 6½ feet to 13 feet from the centre of line, and 130 feet apart in straight sections, and from 80 feet to 100 feet in curves. They are 30 feet high, and are let 6½ feet into the ground. In Florence they consist of ornamental cast-iron columns, with brackets, Fig. 349, the insulators being fixed at the top; but in the open and up to Fiesole, timber poles are used. The contact wire, of silicon bronze, 5 millimetres, or ⅕-inch thick (No. 4, B.W.G.), is suspended over the centre of the way, 20 feet above the level of the rails, from the brackets of the iron columns or poles, when the line runs alongside the road; and from transverse wires

The Florence and Fiesole Electrical

This line is 7·3 kilometres, or 4½ miles, long, being
to 1 in 12½; and is the first continuous steep-
lway in Europe. It is worked on the overhead
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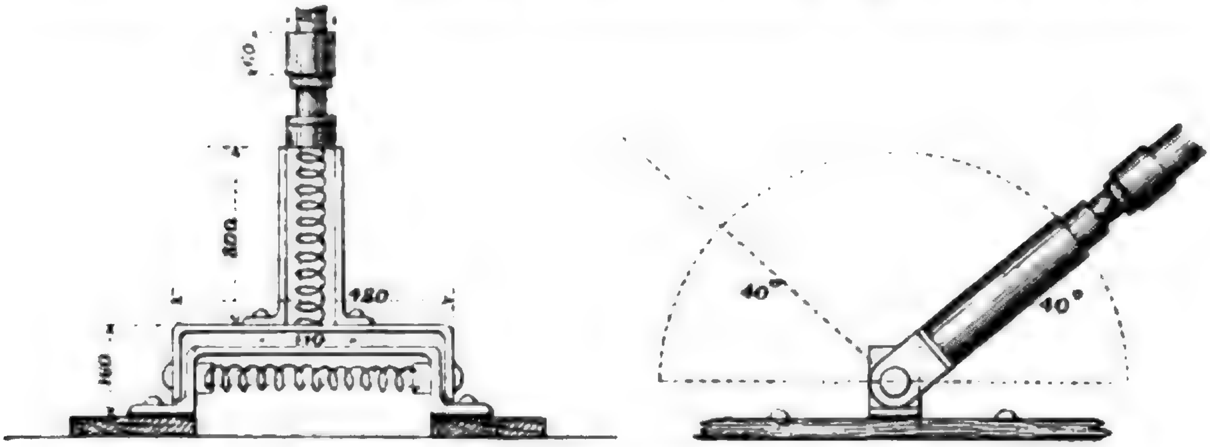
over the centre of the way, 20 feet above the
from the brackets of the iron columns
line runs alongside the road; and from

347. Fiesole
Railway
of Boiler.

hung from poles on both sides on the road, where the way is situated in the middle of the roadway. In curves, the contact wire is kept in position by diagonal wires as well. The current is transmitted by the main conductor to the contact wire in sections of about 130 feet; with two subsidiary conductors connected with the main conductor, between St. Gervasio and Fiesole. From the overhead wires the current passes through the trolley and motors of the car to the rails, which form the return-circuit. To insure perfect continuity of the circuit, the rails are connected at each joint by a copper wire fixed to small iron pins which pass through the flanges of the rail. Earth-plates are not used.

The small trolley wheel is 2 inches in diameter, and it runs along the lower surface of the contact-wire carried on a tubular pole 15 feet high, 2 inches in mean diameter, which has a lateral play of 3 feet, and a vertical play of 10 feet, and is reversible, its lower end being fitted to a channel-iron riveted to the centre of the roof of the car (Figs. 350, 352, and 353). When the train is in motion in one direction, the trolley pole is inclined in the opposite direction at an angle of about 40°, projecting beyond the back platform, and brought under the control of the guard by means of a loose cord suspended from it.



FIGS. 352, 353. Fiesole Railway: Trolley Pole.

Each car, Figs. 350, 351, carries two motors, of which the armatures consist of twenty-eight spirals of ·64 ohm. resistance each, the maximum efficiency being 90 per cent., less 25 per cent. due to loss by gearing. They are suspended between the car-axles and a transverse channel-iron riveted to the frame. The motion is transmitted to the car-wheels by toothed gearing, Fig. 354, in the ratio of 1 to 12. The dimensions are given in the following tablet. The smaller wheels of each pair are of bronze, in view of the greater stress on steep inclines. They are encased in metal boxes.

Pinion.	Dimensions of teeth.			Diameter at pitch line.
	Depth.	Width.	Length.	
No.	Millimetres.	Millimetres.	Millimetres.	Millimetres.
1	10	7·5	95	100
2	10	7·5	95	400
3	15	10·0	100	140
4	15	10·0	100	420

The motors are placed immediately under the floor, as in Fig. 351. They are of the Sprague type, and they have three conductors which can be coupled in seven different ways, by means of the regulator, Fig. 355, on the platform—so varying the speed. The motors are tested to develop up to 20 horse-power each, or 40 horse-power for both; which at 736 volt amperes per horse-power, and a potential of 500 volts, is equal to 60 amperes, derived from the main conductor, and represents (40 × 75=)

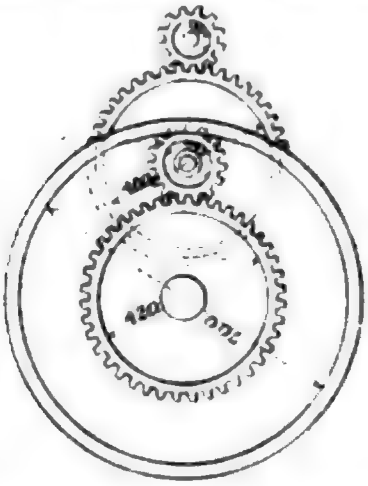


FIG. 354. Fiesole Railway: Car. Gearing of Motor.

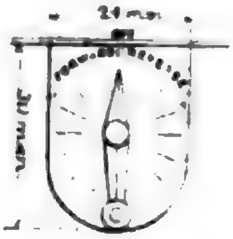


FIG. 355. Fiesole Railway: Regulator of Car.

3000 metre-kilogrammes, less 25 per cent. for friction by gearing, or 2250 metre-kilogrammes, equal to $\frac{2250}{75}$, or 30 effective horse-power. The effective powers required on the three sections into which for convenience the line is divided, at the regulation speeds of 14, 10, and 8 kilometres per hour, are respectively 4, 16, 20 horse-power only.

The cars are 14.4 feet long, or 20 feet long including the end platforms, 8½ feet wide outside, seated for 24 passengers. The total height is 10 feet above the rails. The wheel-base is 6 feet long. The weight empty is 5 tons; full, 7½ tons. The body of the car rests on four vertical springs. Curves of 14 metres and 12 metres can be passed with perfect safety. Each platform is fitted with a regulator disk, a sand-valve handle, a mechanical chain-brake, and an electric safety-brake. The roof is 10 feet below the contact-wire.

The cost of construction was as follows:—

	£
Works, way, sidings, buildings, stations, and accessories	13,000
Three boilers and three engines, of 80 horse-power each	4,000
Electric plant, three dynamos, twelve car-frames, with motors, wires, &c.	9,000
Twelve passenger-cars	1,000
Telephone and sundries	1,000
	28,000

Or at the rate of £6,144 per mile.

The working expenditure, based on an average of 375 car-miles run per day, is as follows:—

	Lire per day.	Pence per car-mile.
Traffic (guards, inspectors)	38	0·96
Maintenance	27	0·68
Motive power, including car drivers	110	2·80
Depreciation and renewals of boilers, electric plant, cars, line	81	2·08
General charges	41	1·05
Total lire	297	7·58

Mr. Sheibner estimates that if instead of by electricity, the line were worked by eight ordinary 16-ton locomotives, or by eight 12-ton combined adhesion and rack engines, the total cost of construction would have been as follows:—

	Adhesion. £	Adhesion and rack. £
Works	13,000	13,000
Rack, 2·7 kilometres	—	4,000
Eight engines	5,000	8,000
Twelve carriages	2,400	2,400
Sundries	1,000	1,000
	21,400	28,400

The expenditure per day of one of these engines, running 100 kilometres or 60 miles per day, is:—

	Lire.
Fuel, 600 kilogrammes, 40 lire per ton . . .	24
Oil and repairs	6
Driver and stoker	9
Total	33 = £1·32

Hence, for six engines running, with two in reserve, the cost is 214 lire per day $= \dfrac{214 \times 100}{600 \text{ kilos.}} = 35{\cdot}7$ centimes per train-kilometre, or 5.46 pence per train-mile, which is nearly double the cost for electric motive power.

CHAPTER VI.

THE LIVERPOOL OVERHEAD RAILWAY.

THIS railway* is 6⅓ miles in length, of which 5⅛ miles are now worked (March, 1894). Thirteen stations are in use, and four are to be added. The gradients are easy, excepting two short gradients of 1 in 40, under-crossing a coal line. The sharpest curves are of 7 chains radius. The line is carried on cast-iron columns, of which the normal span is 50 feet, with bow-string lattice and plate girders.

The way consists of flat-bottomed steel rails, weighing 56 lbs. per yard, fixed on longitudinal timbers which are held down to the floor by iron lugs riveted on to it, and oak keys, Figs. 356, 357. On the curves these timbers vary in thickness according to the necessary super-elevation of rail. The rails are fixed by spikes and fang-bolts, special care being taken in fixing them to avoid metallic contact with the main structure. The electrical conductor, which consists of a steel bar 4 square inches in section, of ⊓ form, is placed midway between the rails of each line, and is carried on porcelain insulators supported by cross-timbers. The joints are provided with copper connections, and since the return current is brought back through the rails, a bent iron bond riveted through the web of the rails is fixed at each fish-joint. Cables laid under ground from the railway to the generating-station, a distance of 60 yards, connect the conductors and the rails with the dynamos.

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* See a paper on "The Liverpool Overhead Railway," by Messrs. J. H. Greathead, Francis Fox, and Thomas Parker, in the *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxvii., 1893–94.

One train consists of two carriages, each 45 feet long and 8½ feet wide, on two bogies, 32 feet apart from centre-pin to centre-pin, with 2-feet 9-inch wheels, 7-feet wheel-base and pressed steel frames. The carriages are all exactly alike and contain accommodation for sixteen first-class and forty-one second-class passengers in each carriage, with three side doors and a passage from end to end. The first-class passengers are at one end of the carriage, and the driver's box with switches, etc., is at the other. When the two carriages are coupled together to form a train, the driver's boxes are at the extreme ends and the two first-class compartments consequently together in the middle of the train. A small door through the contiguous ends of the carriages enables the guard or attendant to pass from end to end of the train.

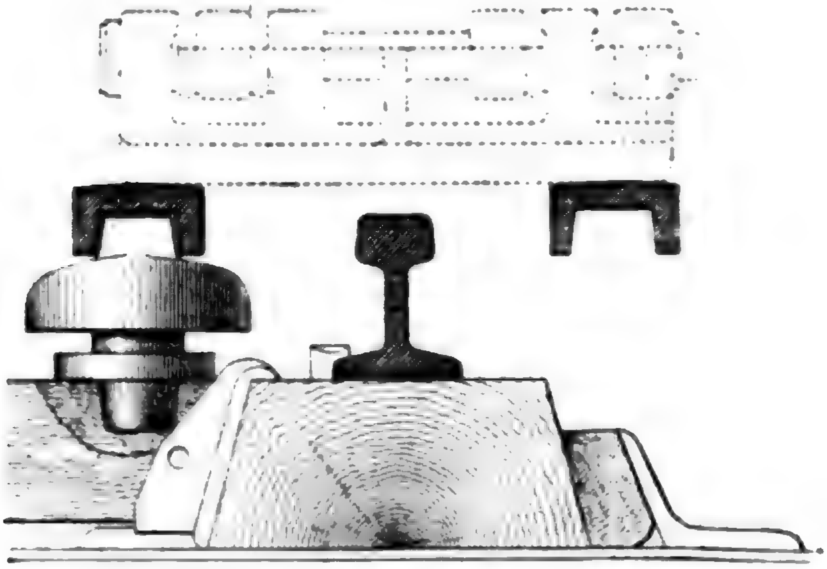

FIG. 356.—Liverpool Overhead Railway: Section of Conductor Crossing.

The motors, one at each end of the train, are controlled from either end; the driver, of course, always travelling at the front end of the train and changing ends upon arrival at a terminus, carrying with him a key without which the motors cannot be operated. In a train thus arranged one driver and one conductor constitute the train staff, the guard as well as the driver having it in his power to cut off the current from the motors and to apply the brakes.

The trains are fitted with the Westinghouse automatic brake, deriving its supply of compressed air from a reservoir on the train. The reservoir has a capacity sufficient for two complete journeys and is recharged each journey from a receiver placed at the terminus at the north end of the line.

A hand-brake is also provided at each end of the train.

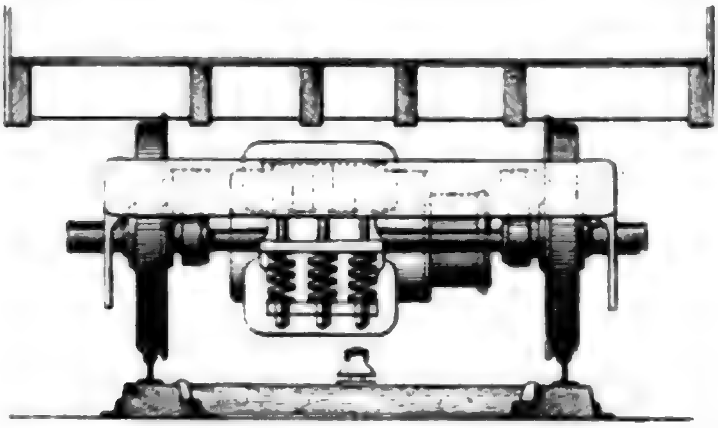

FIG. 357.—Liverpool Overhead Railway: Bogie with Armature. Transverse section.

The generating-station, Plate VIII. (Figs. 358, 359), is under the arches of the coal-railway of the Lancashire and Yorkshire Railway Company at Wellington Dock. The coal, bituminous slate, is here tipped direct from the railway trucks into large hoppers placed over the boilers, and is distributed by means of a conveyor to the shoots of the Vicars mechanical stokers with which the furnaces are fitted. There is thus no handling of the coal. Water from the adjacent dock is used for condensing, and the town water for the boilers.

The boilers are of the double-flue Lancashire type with cross tubes; they are of steel, 6 in number, each 8 feet in diameter by 30 feet long, with a working-pressure of 120 lbs. per square inch, and Green economisers in duplicate are fixed in the main flues. The steam and feed-pipe ranges are also in duplicate. The engines are four in number, each consisting of a pair of horizontal compound condensing engines, built by Messrs. Musgrave & Co. of Bolton, who contracted with the Electric Construction Corporation to supply the engines and boilers complete, and with the Company to erect the chimney shaft (165 feet high), foundations of boilers, engines, etc. The high-pressure cylinders are 15½ inches, and the low-pressure 31 inches in diameter, with a stroke of 36 inches, fitted with Corliss valves driven by Trip gear, acted on directly by the governor. Each engine will develop 400 I.H.P. at 100 revolutions per minute with 120 lbs. boiler-pressure. All the engines exhaust to one condenser of the tubular surface type. The centrifugal circulating pump and air-pumps are driven by a Musgrave "No-dead-centre" vertical compound engine, and the condensing-plant is in duplicate.

Each engine drives an Elwell-Parker dynamo, from which the current is conveyed north and south along each line of the railway by the steel conductor already described. Hinged collectors of cast iron, sliding upon this conductor, the upper surface of which is about ¾ inch higher than rail level, allow the current, when required, to pass through the motors and to return by the wheels and the rails to the dynamos. At the crossings the conductor is bent to form wings parallel to the rail to be crossed, in the same way as is usually done at rail crossings.

The empty train weighs 31 tons 2¼ cwt., of which the electrical equipment for locomotion weighs 6 tons 7 cwt. With all seats occupied by passengers, the total weight is about 38 tons 6 cwt., but on occasions the standing-room in the train is also fully occupied, bringing the weight to perhaps 50 tons. The weight of locomotive equipment is thus about 125 lbs. per passenger, and about 20 per cent. of the total weight of the train with all seats occupied, each passenger being taken at 140 lbs. weight. A comparison of these figures with those of trains on other railways using electric and steam-locomotives is given in the next table:—

d Green economisers in duplicate are fixed in the
e steam and feed-pipe ranges are also in duplic
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20 per cent. of the total weight of the train wh
ed, each passenger being taken at 140 lbs. weight.
of these figures with those of trains on other rai
and steam-locomotives is given in the next tab

COMPARATIVE WEIGHT AND PASSENGERS OF ELECTRIC AND STEAM CONVEYANCE.

	Electric Motors.	Electric Locomotives.	Steam Locomotives.	
	Liverpool Overhead Railway.	City and South London Railway.	Manhatta Railway, New York.	Gt. Northern Railway, Suburban Train.
	T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.
Weight of motors or locomotive	6 7 0	10 7 0	23 4 0	53 10 0
Number of passenger-seats in train	114	96	230	414
Weight of motors or locomotive per passenger, in lbs.	125	241	217	290
Weight of full train (all seats occupied)	T. C. Q. 38 5 2	T. C. Q. 37 7 0	T. C. Q. 104 1 0	T. C. Q. 188 11 0
Weight of motors or locomotive relatively to weight of full train, *ex* motors or locomotives, per cent.	20	38	29	40
Average weight of empty carriages (*ex* motors) per passenger seat, in lbs.	487	490	615	590
Weight of full train per passenger, in lbs.	752	871	972	1,020

For the generating-plant there are four dynamos of the double limb type, each having a normal output of 475 amperes at 500 volts, at 420 revolutions per minute, or say 1,200 electric H.P. in all. The arrangement of the generating-plant is shown in Plate VIII. The dynamos are formed with a magnetic circuit above and below the armature, the poles being cut through horizontally along the centre line to allow the upper part to be lifted readily. They are shunt-wound, of "drum" type, with stranded conductors. The resistance of the armature is 0·01 ohm, and that of the shunt is 75 ohms, the electrical efficiency of the machines being 97·7 per cent. The armature and shaft weigh

3 tons, and the complete machines 21½ tons each. Each dynamo is driven by nineteen 1¼-inch cotton ropes, from a horizontal compound engine, indicating 400 H.P. at full load.

The armature-shaft carries a half-coupling by which it is connected to the pulley-shaft, which runs between two bearings; the armatures can thus be easily removed without disturbing the pulley and ropes. The dynamos are built on lines sufficiently massive to be capable of producing a much greater output than the normal for a short period without injury. They can check the engines in the event of too heavy a call being made upon them, and so prevent any serious damage occurring to them, in case of a continuous short-circuit on the line.

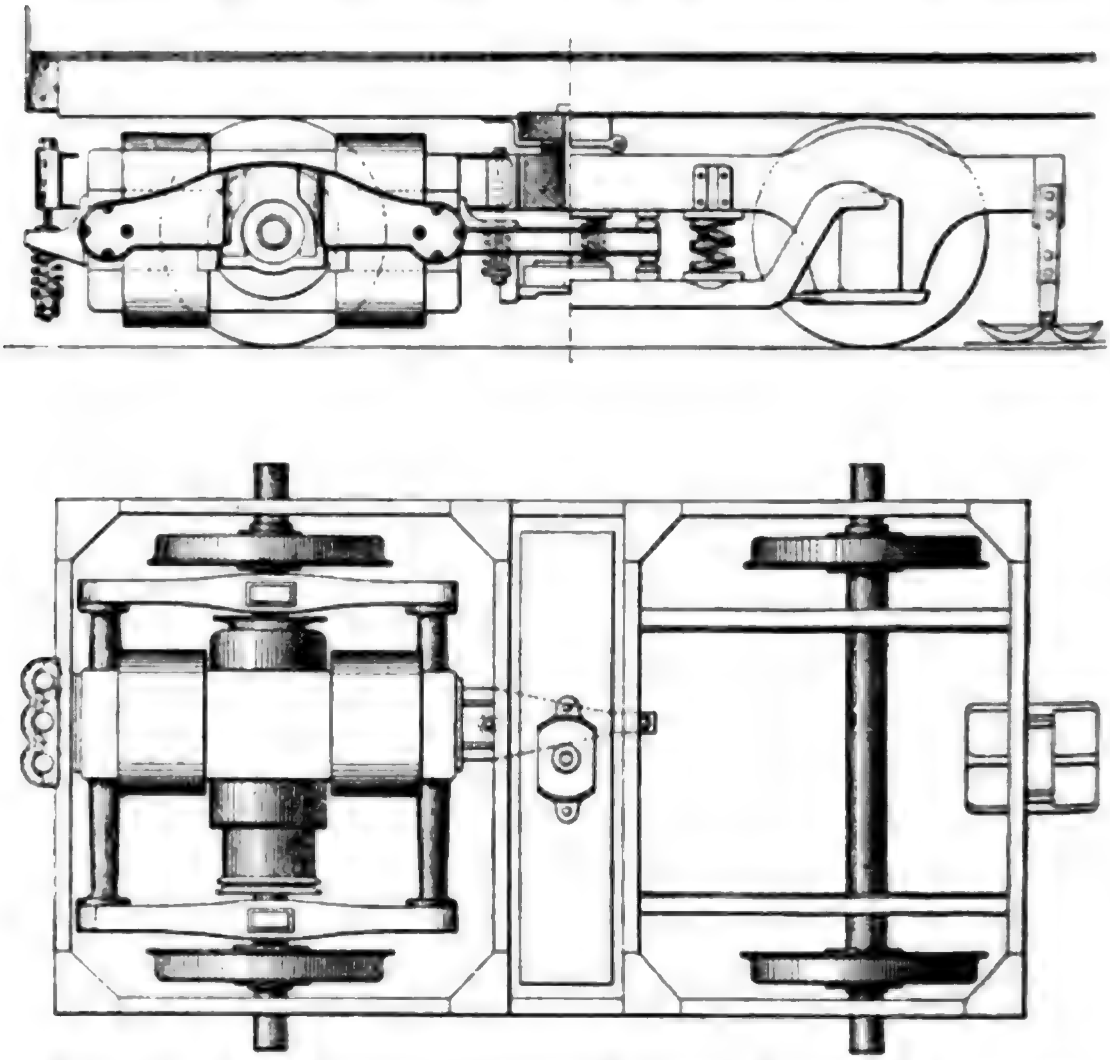
The current from each dynamo is connected to common omnibus bars through an ammeter and automatic magnetic cut-out, so that all can work in parallel. These cut-outs, which protect the generating plant, are also used as switches, and are thus always kept in working order. A similar form of switch is used on the cars, and the guard can, independently of the driver, by applying the brakes, cut the current off the motors, and bring the train to a standstill. From the omnibus bars the current passes through a main magnetic cut-out (adjusted to break circuit with a current of 3,000 to 4,000 amperes) to the centre conductor, from which the moving trains collect their current, by four $\frac{37}{13}$ "Callender" lead-sheathed and steel-armoured cables laid under the road between the generating-station and the overhead structure.

The main conductor is of steel, 4 square inches in section, as already stated, rolled in lengths of 32 feet 6 inches, and weighs about 40 lbs. per lineal yard. It is supported between the main rails on wooden cross-sleepers and rests on porcelain insulators. The steel channel is not rigidly attached to the insulators in any way, and is supported by them at every 7 feet 6 inches, except where joints occur in the conductor, in which cases the insulators are 2 feet 6 inches apart. The lengths of conductor are electrically connected by flexible copper straps. There are no feeders, and the return circuit is through the rails, which are united by wrought-iron bonds riveted to the web and bridging across the fish-plates. All four rails are cross-bonded at the stations, but are insulated from the structure by longitudinal sleepers. They weigh 56 lbs. per lineal yard. The return circuit has thus a sectional area of approximately 22 square inches. At each station there is a cross-over road, and, in order to surmount the difficulty of carrying the charged conductor past the main rails at these points, it was broken, and each end was bent parallel to the main rail for some distance on each side of it, being electrically connected under the rail, and fixed ¾ inch above it. The collectors on the car were made wide enough to bridge across the gap thus formed without breaking the circuit.

Each car is an independent unit, having a motor built with the armature direct upon the front axle of each bogie, on Mr. Eickemeyer's system (Figs. 360, 361). The magnets are maintained in correct relation to the armature-axle by two cast-iron flitch-frames, carried by forged extensions of the magnet-yokes. The weight of the magnets is taken off the axles by means of adjustable springs suspended from the bogie-frame and attached to brackets at each end of the motor. To retain the magnets in a correct horizontal position, a lever-arm projects from the inside end of the motor, and is attached on the bogie-truck beyond the bolster by rubber spring pads, top and bottom. The motors are series-wound, and develop 40 H.P. for any length of time without undue heating. The armature-resistance is 0·67 ohm, and that of the field-magnet coils is 0·37 ohm. The tractive force of each motor at the rim of the wheels (2 feet 9 inches in diameter) with 100 amperes exceeds 1,450 lbs. (about 87 lbs. per ton of train). The weight of each motor with its axle, without the wheels, is 3 tons, and that of the motor-truck complete is 5 tons 7 cwt.

According to the results of tests at the generating-station, the mean efficiency, or ratio of E.H.P. to I.H.P. was 88 per cent. The tests lasted over 3½ hours; the coal consumed was 4,032 lbs. Total E.H.P. hours, 1,195; coal per E.H.P. hour, 3·37 lbs.; coal per I.H.P. hour, 2·96 lbs.

The power absorbed by a train during an experimental run covering the length of line at present open (5¼ miles) in twenty-four minutes fifty-seven seconds, with intervals of twenty-five seconds stoppage at the stations, or an average running speed of 15·1 miles per hour. Also during one journey performed in twenty-three minutes forty-seven seconds, or, at the rate of 16·1 miles per hour.



FIGS. 360, 361.—Liverpool Overhead Railway: Bogie with Armature. Elevation and Plan.

The particulars of these trials are given below:—

MARCH 5TH, 1893. FIRST JOURNEY.

Herculaneum to Alexandra (return). One train on line.

Loaded with 8 tons (iron weights).
Total time on journey, 24 minutes 57 seconds.

Total time current is on car, 17 minutes 7 seconds.
,, ,, train is standing, 4 minutes 35 seconds.
Total distance run, 9,030·4 yards = 5 miles 230 yards, say 5⅛ miles.
Average speed while running, 15 miles per hour.
,, ,, including stops, 12·3 miles per hour.
Average current per train while running, 82·7 amperes, including stop, 67·3 amperes.
,, electrical H.P. per train while running, 54·4 electrical H.P., including stop, 44·4 electrical H.P.
,, electromotive force, 485·2 volts on car.

MARCH 5TH, 1893. SECOND JOURNEY.

Herculaneum to Alexandra (return). One train on line.

Loaded with 8 tons (iron weights).
Total time on journey, 23 minutes 47 seconds.
,, ,, current is on car, 15 minutes 18 seconds.
,, ,, train is standing, 4 minutes 40 seconds.
,, distance run, 9,030·4 yards, say 5⅛ miles.
Average speed while running, 16·1 miles per hour.
,, ,, including stops, 13 miles per hour.
,, current per train while running, 90·8 amperes, including stops, 73 amperes.
,, electrical H.P. per train while running, 57·1 electrical H.P., including stops, 46 electrical H.P.
,, electromotive force on car, 484 volts.

The weight of a car complete without passengers is 15½ tons. For the test each car was loaded with 4 tons, making the total weight of the train 39 tons. The average power absorbed was 44·4 E.H.P. at 15·1 miles per hour, and 46 E.H.P. at 16·1 miles per hour.

The quantity of coal consumed for all purposes per train-mile was :—

	Lbs.
April	25·16
May	20·03
June	18·97
July	18·27
August	16·95
September	17·20

The composition of the coal, Lancashire small slack, was as follows:—

	Per Cent.
Fixed Carbon	70·08
Volatile Hydrocarbon	16·47
Sulphur	1·92
Moisture	3·01
Ash	8·51

Its calorific value is approximately 75 per cent. of that of best Welsh coal. The price of the slack which was used until the latter part of August was 5s. 10d. per ton, but since that date, owing to the strike in the coal trade, coal has been procured from various sources at price ranging up to 17s. 6d. per ton.

Cost of Working on Liverpool Overhead Railway, including Lighting of Stations and Signals.

	Pence per Train-Mile.		
	July.	August.	Sept.
Supervision	0·416	0·416	0·416
Generating-Station, Wages	0·618	0·590	0·628
Drivers' Wages	1·076	1·043	1·058
Coal	0·589	0·718	1·230
Oil, Waste, Grease	0·140	0·139	0·129
Water	0·010	0·013	0·015
Stores and Sundries	0·049	0·105	0·115
Cleaning and Repairs, &c., at the Car-Shed — Wages	0·545	0·521	0·539
Cleaning and Repairs, &c., at the Car-Shed — Material	0·284	0·430	0·221
Total	3·727	3·975	4·351
Allowance for Signals and Lighting	0·286	0·271	0·276
Cost of Running	3·441	3·704	4·075
Train Mileage	39,250	41,430	40,640

CHAPTER VII.

THE ROUNDHAY (LEEDS) ELECTRIC TRAMWAY.

THIS line is an example of the Thomson-Houston system. The most distinctive feature of the installation is the fact that it is carried out entirely in accordance with current American practice, and it is interesting to see how far that practice is applicable to English conditions.* Although the line meets with the approbation of the residents of the district, the use of single-decked cars of the American type, seating only twenty-two passengers each, proves to be a mistake. Double-decked cars might be used without difficulty, but at the time the line was constructed these were not procurable in time, and their importance was not recognised.

The line, which covers about three miles of ground, is more or less a suburban one, starting about a mile from the centre of Leeds, and running out to Roundhay Park. It is nearly straight, with the exception of the Park end, where there is a balloon loop, which avoids changing the direction of the cars at that end. This arrangement was made originally for steam-trams, and is not at all essential for the electric system. There are two miles of double track and a branch line of a mile and a quarter of single track, with passing places, making a total of 5¼ miles of track. The maximum gradient (of which there are two instances, each about a quarter of a mile long) is 1 in 20. There are several other less gradients; in fact, the line is practically a continuous gradient from the city terminus to the park.

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* For the materials of this Chapter, the Author is indebted to Mr. I. E. Winslow, the Managing Engineer of the line.

The permanent way—which was constructed by the Leeds Corporation several years previously to its adaptation to present purposes—consists of a 98-lb. girder rail of standard section, laid on a bed of concrete 9 ins. thick, extending from curb to curb. The metals are held to gauge by iron tie bars at short intervals. The joints rest upon iron sole plates. This line has been in use for nearly three years with electric traction, and for several years previously with steam traction. The repairs have been nominal. The electric system was installed by the Thomson-Houston International Electric Company in accordance with their standard practice.

A diagrammatic sketch which shows the circuit as in use has already been given in Fig. 340 (p. 562), and the description accompanying that sketch (p. 561) may be referred to with advantage. Here it will be sufficient to say that the current passes out from the dynamo along the trolley wire to the car, and thence passing through the car and motors returns by the rail to the dynamo.

The electric connections of the rails are shown in Fig. 362. There is a tinned copper wire, ·34 inches in diameter, laid between the metals on each track. At the joints a smaller copper wire is keyed to each rail by the peculiar-shaped pin shown in the sketch; this wire is soldered to the main return wire, and, as will be seen, each rail is connected twice to this main return.

The overhead construction is upon what is known as the cross-suspension method—that is, steel poles, as shown in Fig. 363, are set 6 feet into the ground on the curb at each side of the road, and a steel wire stretched between the two poles. These poles are set in concrete to make them as rigid as possible. From the steel wire is suspended a trolley wire, which is of hard-drawn copper wire of ·34 inches.

A very good idea of the way this method of suspension looks in practice will be gathered from Fig. 364 (Plate IX.), which is taken from a photograph of the single-branch line. The details

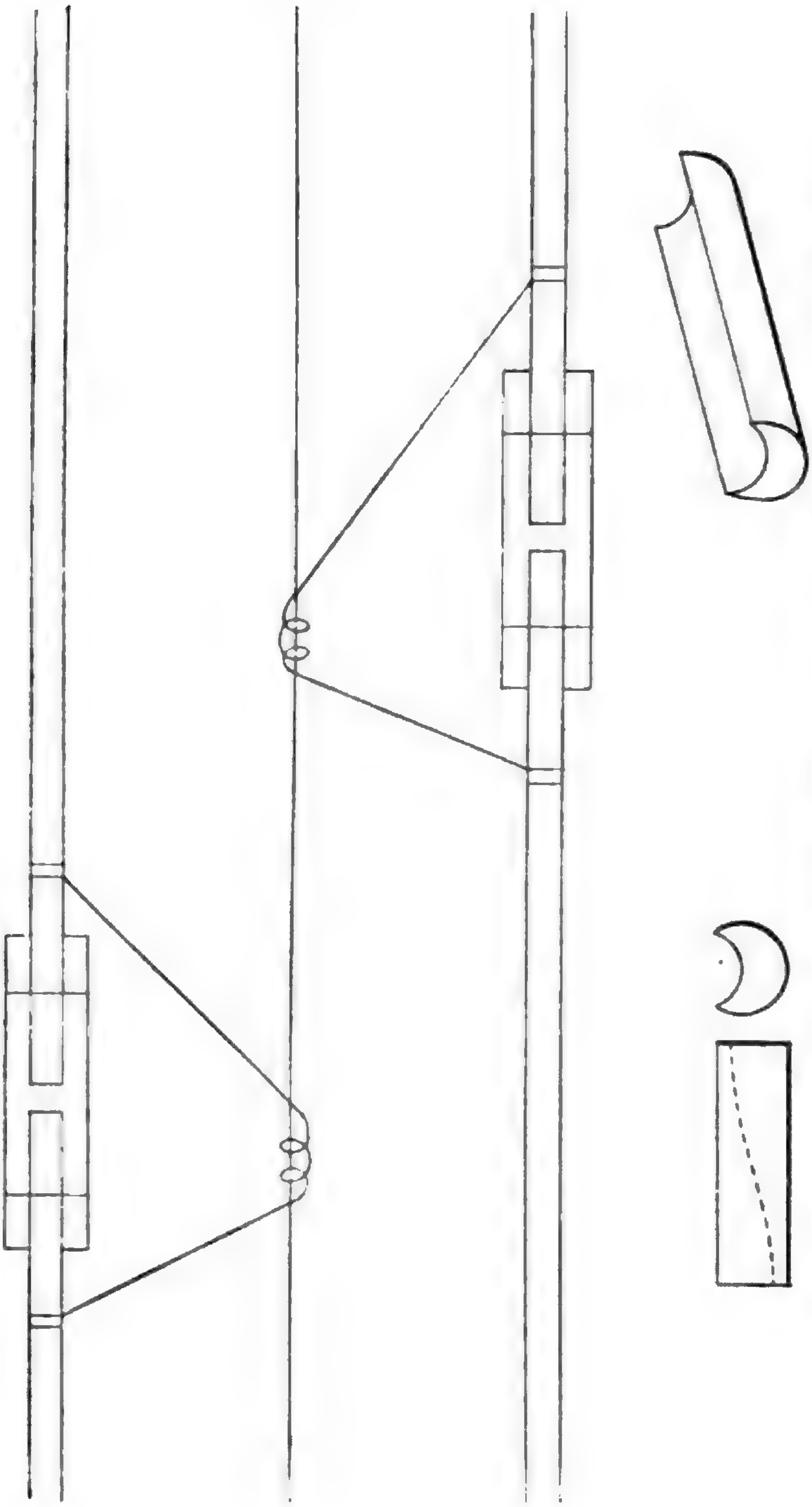


FIG. 362. Diagram showing Electric Connections of Rails (Thomson-Houston system).

of this suspension are shown in Fig. 365, the car, E, being soldered to the trolley wire, D. The insulators C and A are of hard rubber, and their position may be seen in the upper part of the sketch. F and B are the cast-iron hangers which hold the insulator in place. These are of different forms for different line construction, F being used in the curve, and B on the straight line only.

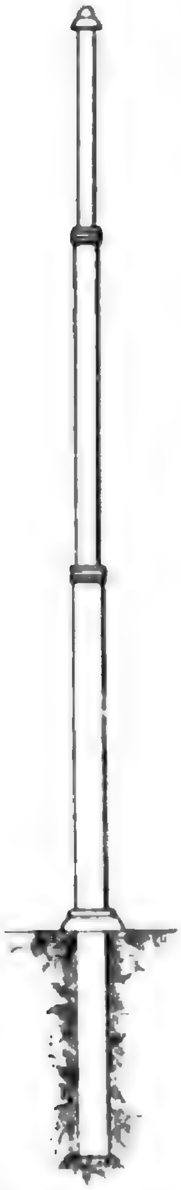


FIG. 363. Steel pole for Overhead Installation.

Fig. 366 is the section of the top of one of the steel poles, showing the method of insulation, A being a wooden plug driven into the top of the pole. This, as will be seen, gives double insulation all over the line.

Figs. 367 and 368 show the devices used for making the trolley-wheel follow the car on a branch line or turn out. They are usually designated as "frogs." These are set slightly out of the centre of the track, so that when the switch in the permanent way sends the car on to the branch line the trolley-wheel is dragged to one side and follows the desired wire.

The cars now in work (July, 1894) are six in number, and are of the standard American pattern, seating 22 passengers each. They make a run of 110 miles a day each, and upon Saturdays, Sundays, and holidays two trail cars are also run, each seating 46 passengers, the motors being of ample power to draw this additional load.

Each car is equipped with two single-reduction motors, each of 15 H.P., as shown in Fig. 369. Fig. 370 will give a better idea of the details. The following particulars will be of interest:—

Weight of motor, without gear or gear cover .	2,060 lbs.
,, armature, with pinion	484 ,,
,, one field-spool	128 ,,

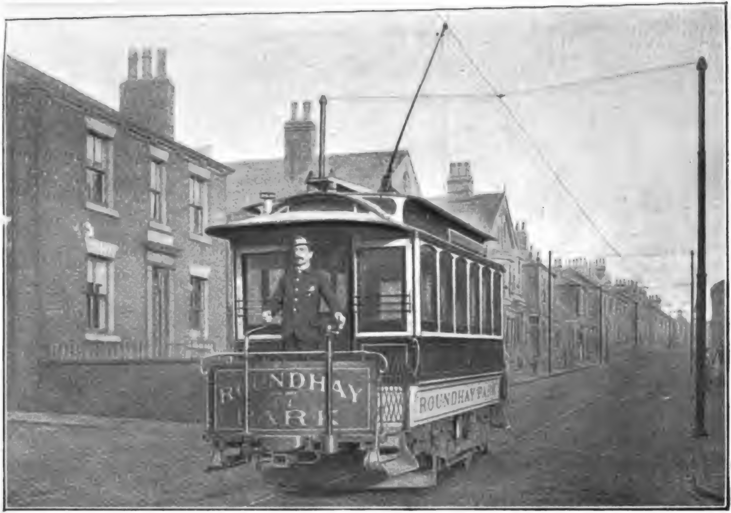

ROUNDHAY PARK
ROUNDHAY PARK

FIG. 364.

THOMSON-HOUSTON SYSTEM OF TROLLEY WIRE SUSPENSION.

[*To face page* 618.

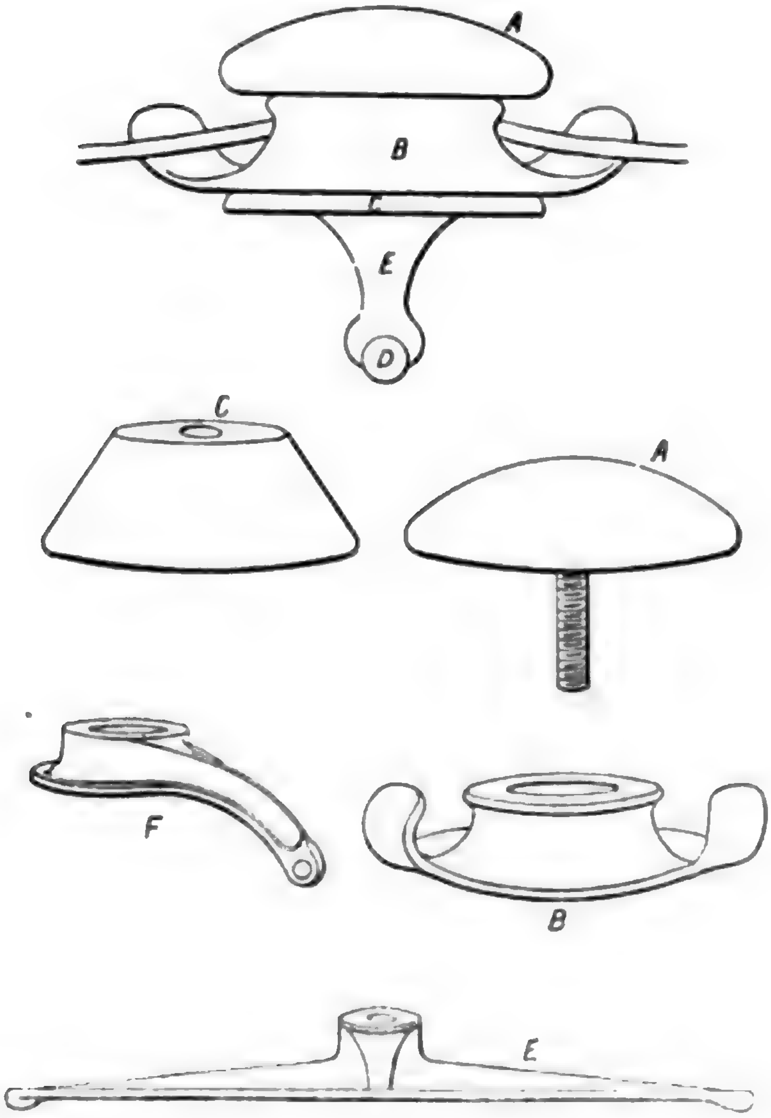

A
B
C
E
D
C
A
F
B
E

FIG. 365. Details of Trolley-wire Suspension.

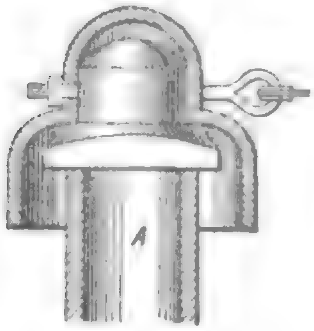
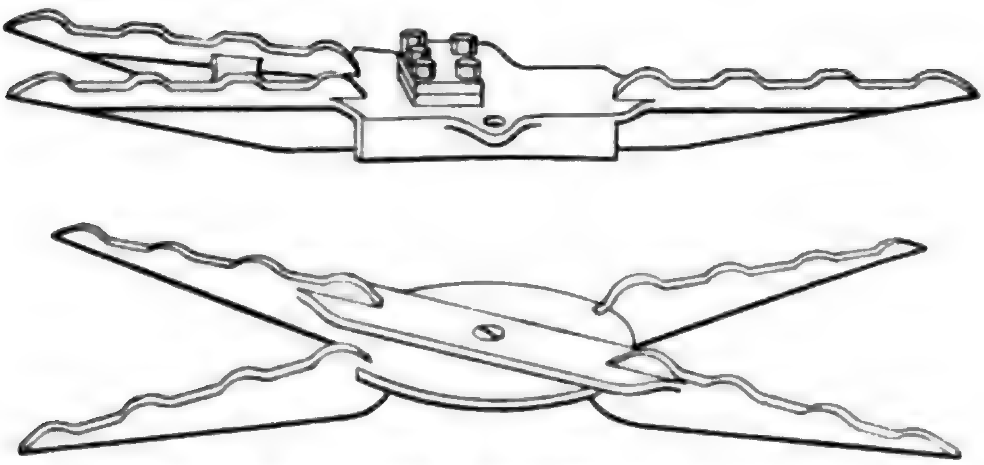


FIG. 366. Section of Top of Steel Pole.



FIGS. 367, 368. "Frogs" for diverting Trolley-wheels.

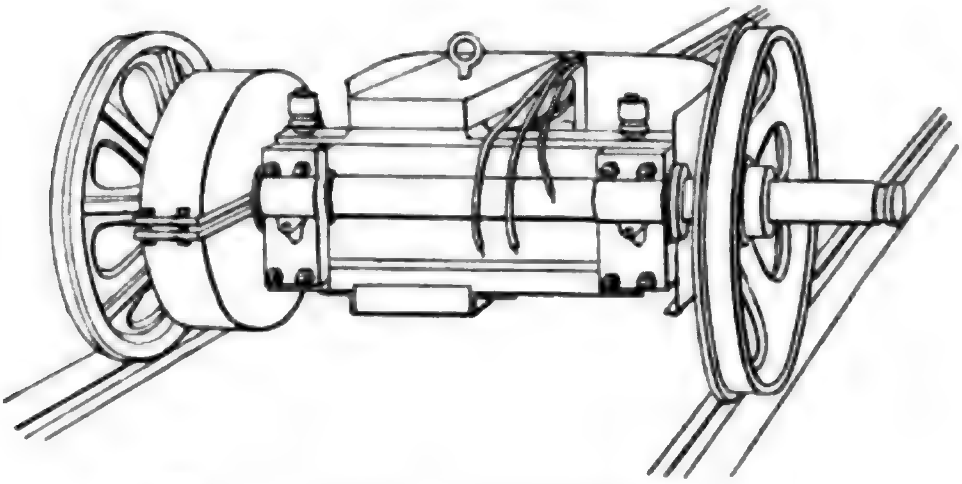


FIG. 369. Single-reduction Motor for Car.

Weight of one pole-piece	270 lbs.
,, frame, including nose-piece . .	693 ,,
,, axle gear	215 ,,
Number of teeth in gear	67
,, ,, in pinion	14
Pitch diameter of gear	$23\frac{1}{8}$ in.
,, ,, in pinion	$4\frac{2}{3}$,,
Speed reduction	4·78

The motors are series-wound, but are in parallel with reference to each other. In running the car, the speed is regulated by means of a rheostat, as shown in Fig. 371. This is composed of thin plates of iron insulated from each other with mica. As will

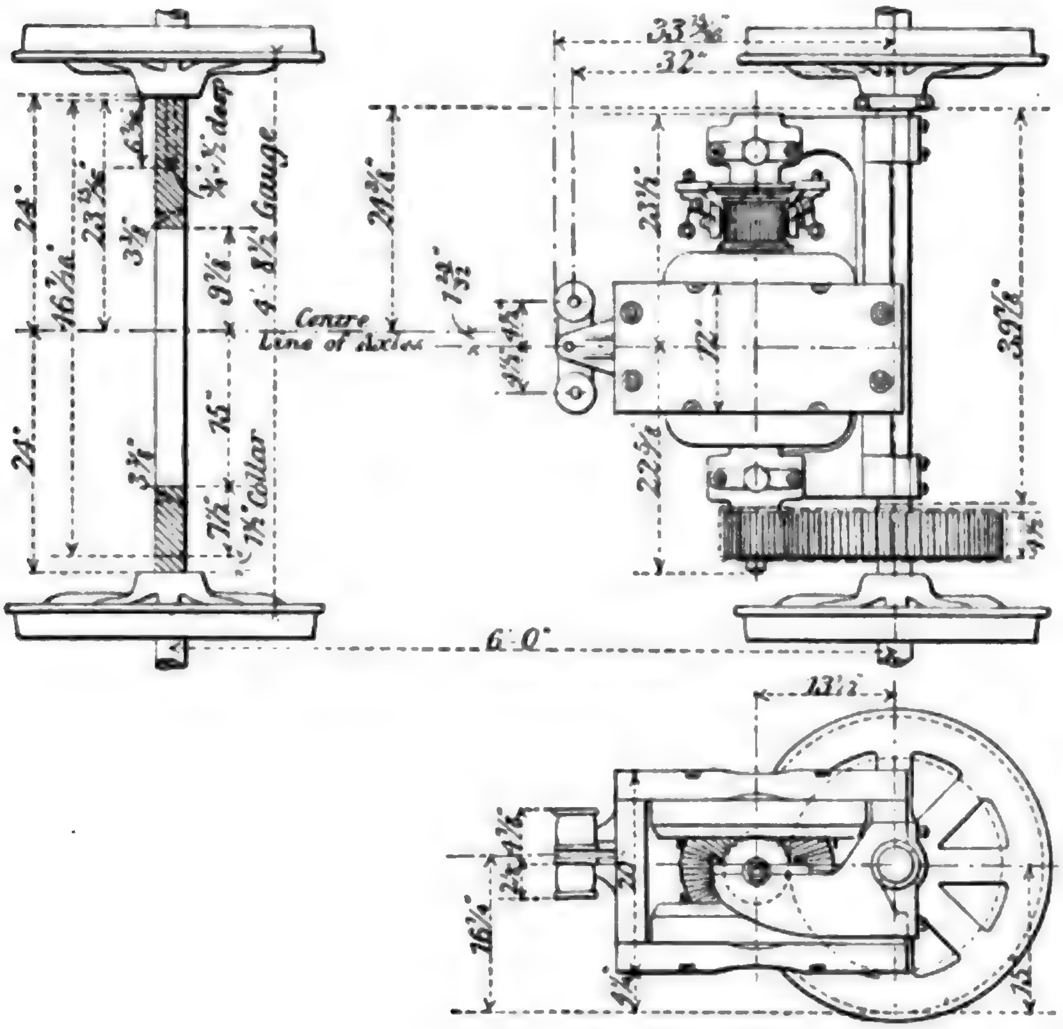

33 5/8"
32"
24"
23 3/4"
24 7/8"
3 3/4"
3/4"×1/2" deep
4' 8 1/2" Gauge
9 7/8"
Centre
Line of Axles
12"
39 7/8"
15"
22 5/8"
7 1/2"
1 1/2" Collar
6' 0"
13 1/2"
16 1/4"
12"

FIG. 370. Details of Single-reduction Motor.

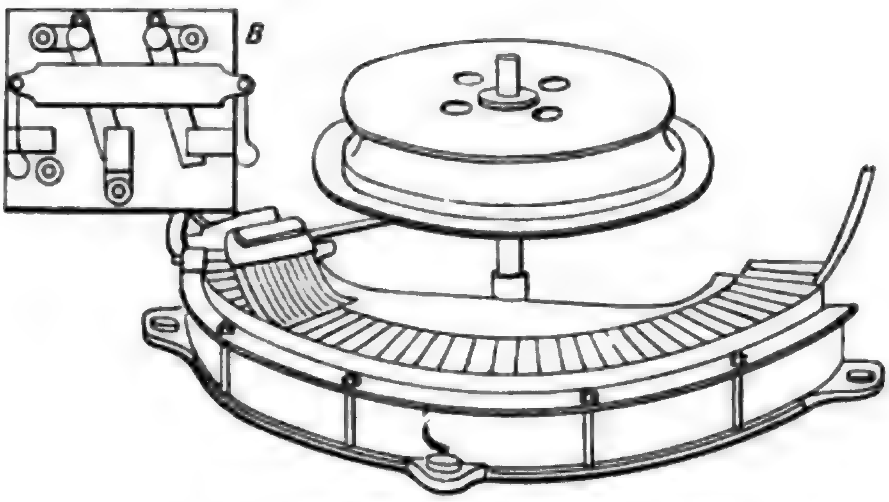


FIG. 371. Rheostat and Reversing Switch.

be seen, it is in the form of a semi-circle, and is exceeding compact for the amount of resistance which it contains. It is operated by steel cable, which passes round the drum and goes to the controller stand (Fig. 372) at each end of the car. These controller stands are fitted with sprocket-wheels and chain, which are attached to the ends of the cables passing round the drum: by this method the amount of resistance is regulated by the man in charge. The direction of the car is changed by means of the reversing switch, B, in Fig. 371, this being controlled in the same manner as the rheostat.

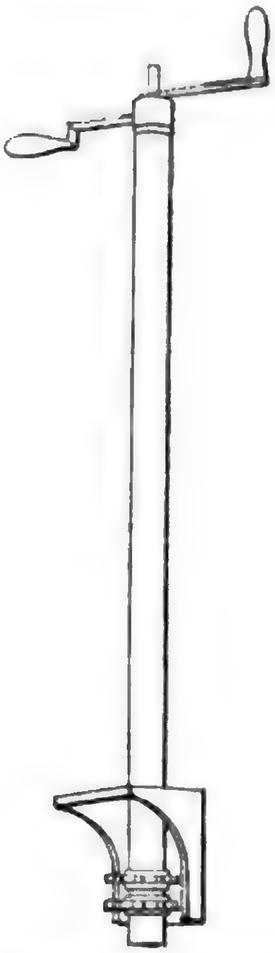


FIG. 372. Controller Stand.

The current is taken from the trolley-wire by the trolley, shown in Fig. 373, a steel pole being used between the stand, B, and the head, A, which carries the trolley-wheel, as seen in the illustration. This stand is free to revolve upon the pivot, which gives any desired lateral play, and the springs press the wheel up against the wire, the tension being regulated by the check-nuts, as shown; this gives a universal motion to the trolley-wheel. It should be noticed that the cam at the base of the trolley is of such a shape that the pressure upon the trolley-wire is always constant, irrespective of the angle which the trolley-wire makes with the pole.

Fig. 374 shows a sketch plan of the station and car-shed. The latter is a brick and iron building, fitted with four tracks, each capable of storing two cars. Under each line track-pits are constructed to admit of the easy inspection of the motors. The engine-house is a temporary structure of corrugated iron, which adjoins the car-shed.

The engine is of the American horizontal type, by Messrs. MacIntosh & Seymour. It has but a single cylinder, 18 × 18½, and indicates 200 H.P., at 100 lbs. of steam and 200 revolutions.

The governor of this engine is situated in the fly-wheel, and is so sensitive that it maintains the speed within 2 per cent., no matter how widely the load fluctuates.

There are two dynamos of the Thomson-Houston manufacture, illustrated in Fig. 375, each of which is capable of delivering 62 units at 300 volts. They are driven by endless perforated leather belts, running at 4,500′ per minute. The switch-board is placed at one end of the station, and contains the necessary instruments for the control of the lines. Carbon brushes are used on both dynamos and motors: these are set radially to the commutators, and are self-feeding.

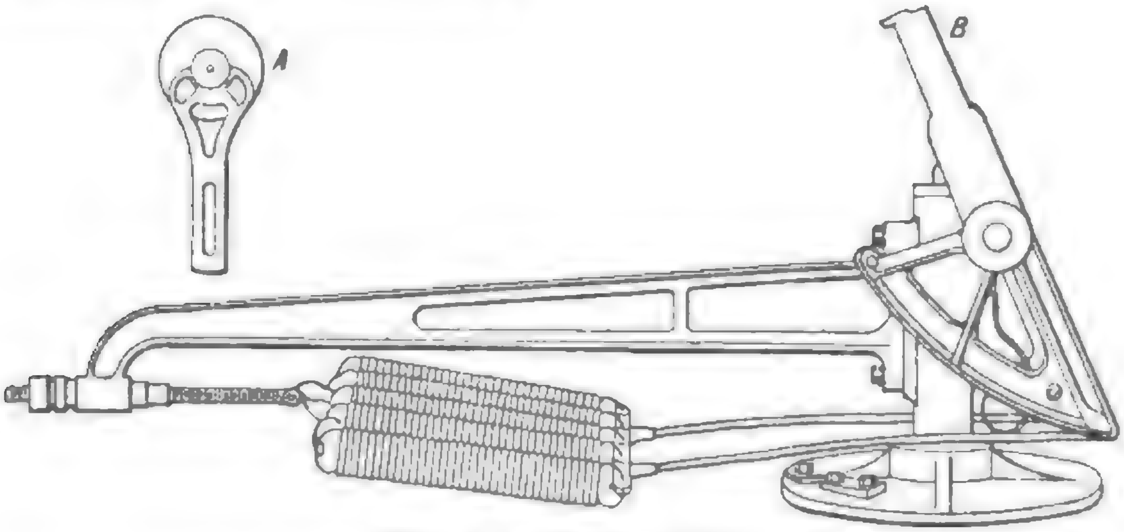


FIG. 373. Trolley Stand.

The boiler is of the water-tube type, by Messrs. Babcock & Wilcox, and is fitted with a mechanical stoker. The feed water is heated by exhaust steam.

The line commenced operations on November 11th, 1891, and up to June 30th, 1894, the total mileage was 505,337.

As no water was available for condensing purposes, it was necessary to use a single-cylinder engine. This engine, as already stated, is capable of indicating 200 H.P. at the most economical point of cut-off, and as the average load does not run beyond 60 H.P., although the maximum load frequently reaches the full capacity of the engine, great economy is not to be expected under such conditions.

As will have been seen from the particulars given with Fig. 370, the weight of the motor is very much greater than the more modern ones manufactured by the same Company, which weigh only 1,500 lbs., as compared with something over 2,000 lbs.; but

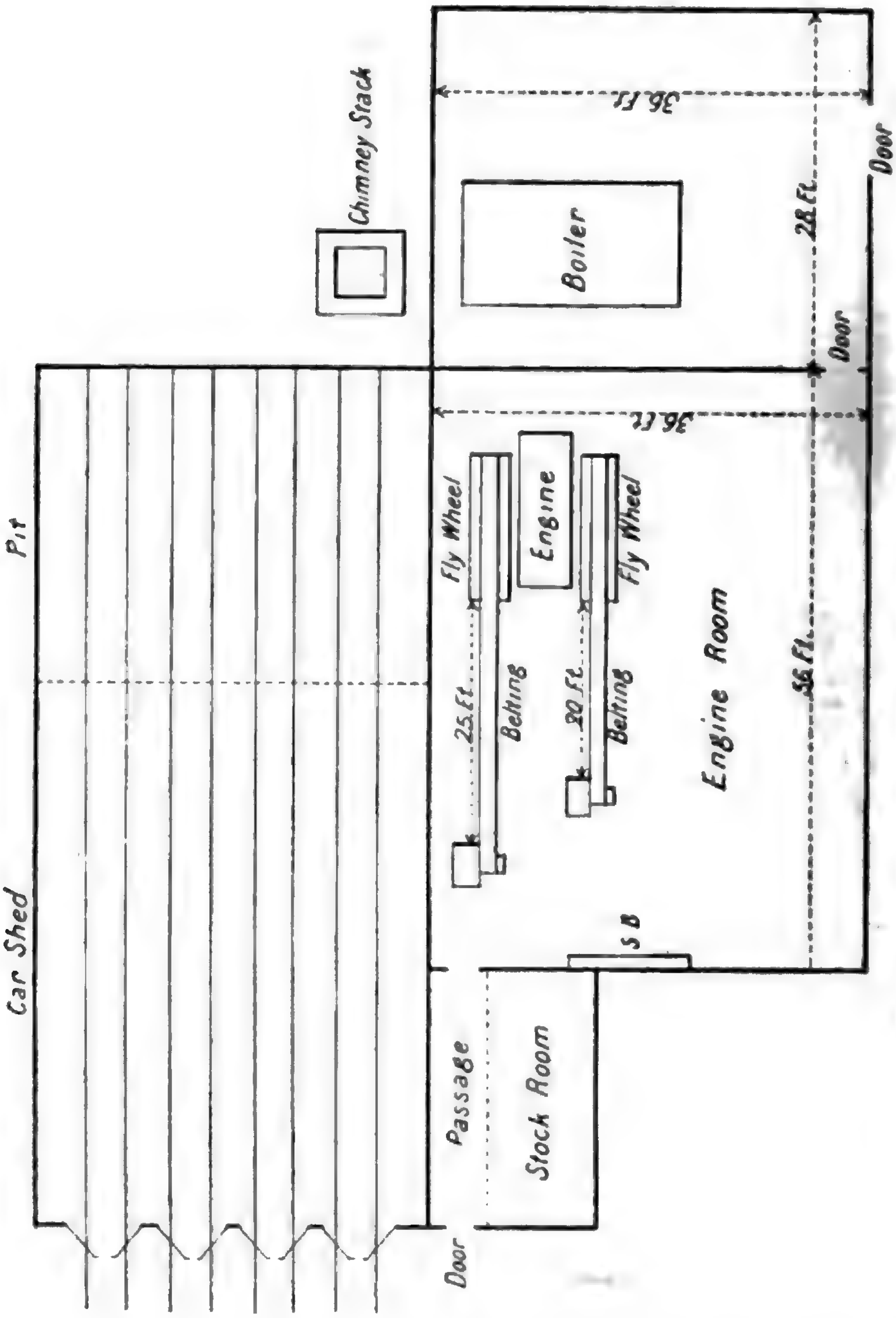

Chimney Stack
36 ft.
Boiler
28 Ft.
Door
Door
36 ft.
Pit
Fly Wheel
Engine
Fly Wheel
Engine Room
25 Ft.
Belting
20 Ft.
Belting
56 Ft.
Car Shed
S B
Passage
Stock Room
Door

FIG. 374. Sketch Plan of Station and Car-shed, Roundhay Electric Tramway.

in spite of these adverse conditions and an exceptionally high rate of wages paid to the conductors and drivers, it has been possible to operate the line for 5·557d. per car mile, the details of which are given in the subjoined table.

Nothing is included in the table for maintenance of the way. This being the property of the Corporation of Leeds, the tramway company are not responsible for the repairs, but they pay to the Corporation a nominal rent—as stated in the table—which would (it is estimated) be about equal to the cost of maintenance.

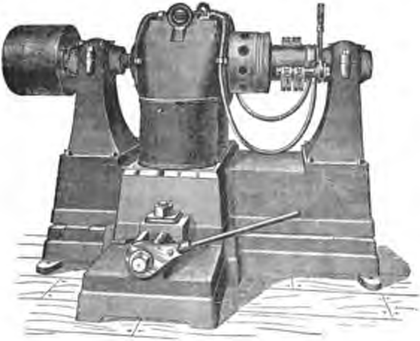


FIG. 375. Thomson-Houston Dynamo.

Again, there is no allowance for depreciation or interest, but depreciation should not be high, as the operating expenses of the road are considerably lower than when it was first put into operation.

The following is the table referred to :—

ROUNDHAY ELECTRIC TRAMWAY.

OPERATION EXPENSES FROM JANUARY 1ST TO JUNE 30TH, 1894.

	£	s.	d.
Wages of drivers	335	1	1½
,, conductors, inspectors, cleaners, etc.	462	18	11½
,, power station	308	15	3
Sundry materials used in car house, etc.	29	8	0½
,, ,, ,, power station	51	17	0
Fuel	333	19	6½
Maintenance of car equipment	161	16	2
,, ,, power station	94	17	1
,, ,, overhead line	18	12	5½
Salaries—office and management	239	12	6
Stationery and printing	15	0	4
Postage and telegrams	5	3	9½
Rent of permanent way	70	10	6
Rent, rates, and taxes	153	8	0
Freight and charges	7	11	2
Insurance	18	14	1
Uniforms, etc.	16	8	3½
Accountant's charges	26	5	0
Miscellaneous expenses	33	0	2½
	£2,382	19	6

Number of miles run	102,914
Cost per car-mile	5·557d.

CHAPTER VIII.

SOUTH STAFFORDSHIRE ELECTRIC TRAMWAY.

THIS tramway line is one of the only two street tramways in England worked by means of an electric current conveyed by bare conductors; the other being the Roundhay line, described in the last chapter. The South Staffordshire line, 8 miles in length, forms part of the South Staffordshire Tramway Company's system, of which the total extent is 23 miles.*

The South Staffordshire Tramway Company serves a district whose population is over 300,000, and the lines form a means of communication between Birmingham and the towns of Walsall, Bloxwich, Wednesbury, Dudley, Tipton, West Bromwich, and Handsworth, by a junction with the Birmingham Central Tramways. The whole system is laid to a gauge of 3½ feet, with 6-inch girder rails upon a bed of concrete; and is paved with granite setts between the rails and for 18 inches outside. It was originally worked by steam locomotives of the Wilkinson type, and with the exception of the 8 miles of electric line all the sections are still so worked. The electric line commences at a junction in Wednesbury with the line from Handsworth, passing through the Market Place, along the Wednesbury Road to the Pleck, where it is joined by another section of the electric line which connects that point with Darlaston. It then passes along the Walsall Road to Walsall Bridge, where it again divides, one section going to

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* The particulars and illustrations here given are taken, by permission, from a paper by Mr. Alfred Dickinson, A.M.C.E., in the *Minutes of the Proceedings of the Institution of Civil Engineers*, vol. cxvii., session 1893—4, part iii.

Rushall and the other to Bloxwich. These sections were originally opened for public traffic as a steam-tramway line in September, 1884, but objections being raised to the use of the steam-engines, the Company received an intimation from the Board of Trade in 1891 that it would not be allowed to continue to work the line by steam. On application to the municipal authorities to sanction the overhead electric-traction system as employed in the United States, the authorities, after visiting Leeds, refused to sanction the system as at work there, chiefly on account of its unsightliness. The system about to be described was designed by Mr. Dickinson to overcome their objections, and they consented to its introduction.

The principle of the American system, whether the trolley-wire be suspended from the span-wires crossing the street, or from brackets upon the poles, necessitates the trolley-wire following the exact curvature of the track. Therefore the number of span-wires, poles, and pull-over wires is practically governed by the physical conditions of the road: the straighter the road the fewer the number of poles, cross wires, and pull-over wires; and the more tortuous the road the greater the number: the maximum being reached in a curve of 90°.

The streets and roads along which the South Staffordshire lines are laid are exceptionally difficult to equip with an overhead wire, because they are very tortuous and of ever-varying widths. There are no fewer than four 90° curves, one of which is of less than 40 feet radius, seven railway bridges, most of them with steep approaches, and one canal bridge with a hog back, to cross which the cars have to ascend a grade of 1 in 16.

The generating-station of the electric line is a substantial brick building situated near to the Birmingham Canal on the Darlaston and Walsall Road. It consists of an engine-room 59 feet long and 45 feet wide, a boiler-house 47 feet long and 39 feet wide, an octagonal chimney stack 120 feet high, and the necessary detached oil-stores and outbuildings. From the canal, a basin has been cut alongside the boiler-house, to permit of the unloading of the coal from boats direct into the stokehole. In the boiler-house there are three Lancashire boilers constructed to work at a pressure of 120 lbs. per square inch. Each boiler is of steel throughout, 30 feet long by 7 feet in diameter, with internal flues 2 feet 9 inches in diameter, each fitted with five cross tubes. No economisers or mechanical stokers are provided.

In the engine-room are three compound horizontal engines and three dynamos. At 100 revolutions per minute, with a boiler-pressure of 120 lbs. per square inch, each engine develops 125 I.H.P. The cylinders, fitted with Corliss valves, are arranged side by side with the fly-wheel driving-drum between them; the high-pressure cylinder is 10½ inches, and the low-pressure 20 inches in diameter, with a stroke 30 inches. The fly-wheel driving-drums are 10 feet in diameter, and are grooved for rope-driving. The dynamos are shunt wound. They have drum armatures, and at 450 revolutions per minute give an output of 260 amperes at 350 volts. They are driven by nine 1½-inch cotton-ropes led direct from the driving-drums to a 2-foot rope-pulley keyed on to a shaft which is coupled to the armature-shaft; when so coupled, this shaft is carried in three bearings, the rope-pulley running between two of them.

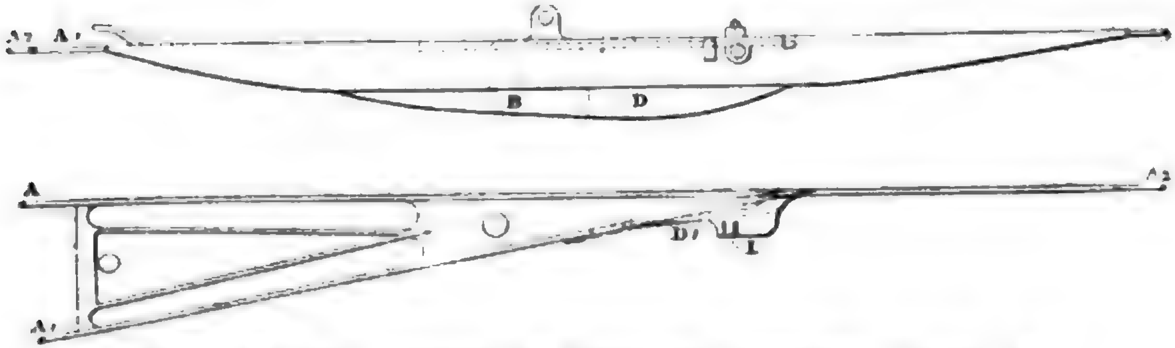
The centre bearing is between the pulley and the armature, an arrangement which permits of the armature being taken out without disturbing the driving-ropes. Special devices have been attached to both the engines and dynamos for continually lubricating the main bearings during the time of running. Upon the main switchboard is arranged, for each dynamo, a voltmeter, an ammeter, resistance-coils and an automatic cut-out switch, the magnet of which is so set that when the current exceeds the safe load it automatically throws out the switch. The connections to and from these switches are so arranged as to allow any two or all three dynamos to be coupled in parallel at will. From the omnibus bar, at the back of the switchboard, runs the lead-sheathed armoured cable-feeder.

This feeder is laid underground into the road, where it is buried near the curb some 15 inches beneath the surface. It extends in the direction of Birchills, near Bloxwich, a distance of 3 miles, in the direction of James Bridge, a quarter of a mile, and from the Pleck it branches off to Wood Green, Wednesbury, a distance of 1¼ mile. The whole of the current from the dynamos is supplied through this feeder, which is tapped at its extremities, and in thirteen places along its length; branch feeders being taken from the main to terminals placed in special boxes fixed in the footpath at the bases of poles situated at distances of about ½ mile apart. Upon each terminal are two slots, and opposite to it, at a distance of about 4 inches, two other terminals are placed, each having a slot. The terminals being insulated one from the other, connection is made between them by movable fuses. The connection between the two single terminals and the trolley-wire overhead is made by a flexible cable carried inside the poles.

The trolley-wire (O. B. W. G.) is of hard-drawn copper. It is suspended at a height of 21 feet above the road from the arms of the poles by clips attached to "Ætna" insulators, at varying distances from the line not exceeding 13 feet. On the trolley-wire at each of these poles, is arranged a special device which insulates one section of it from the adjacent section, a separate feeder going to each. This arrangement allows of any half mile of the line being worked or disconnected independently of the remainder. As the tramway is partly double line and partly single line with turn-outs, of which there are thirty-seven in all, used mostly as passing places for the cars, it was necessary to provide, as in double line, two trolley-wires, and, at the end of each turnout, a switch to permit of the trolley-wheel diverging from the single to the double wire and *vice versâ*. It will therefore be seen that as the trolley-wheel has double flanges, such a switch must be applicable to both a point and a crossing. The device will be understood by reference to Figs. 376, 377.

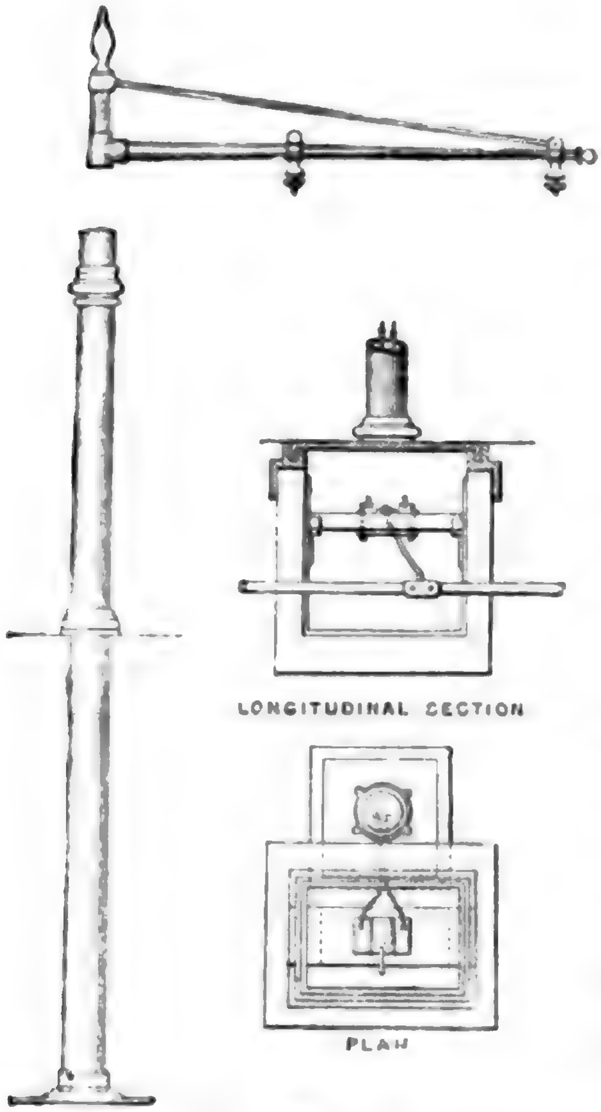
When the trolley-wheel is travelling along the trolley-wire A_1 and is required to reach the trolley-wire A_2, the movable tongue D when closed forms a crossing, as it projects below the tongue B and permits the trolley-wheel to pass under it; but should it be necessary for the trolley-wheel to pass from the trolley-wire A to the trolley-wire A_2, the movable tongue D is pulled over to the position D_1, opening the point and allowing the trolley-wheel a clear passage in the desired direction. When the trolley-wheel is travelling from the wire A_2 to the wire A_1, the movable point D being closed, and projecting below the tongue B, permits the trolley-wheel to cross it and to pass to the wire A_1; and in the case of the trolley-wheel travelling from the wire A to the wire A_1, it passes along the tongue B and opens the point by pushing the movable tongue D to the position D_1—the point being automatically closed after the passage of the trolley-wheel by means of the helical spring I. The same device is used at the branch roads in the various car depôts.

The poles form an important part of any overhead electric installation, as they are always present in the streets. Mr. Dickinson's aim was to design a type which would possess a maximum amount of strength with a minimum weight, and at the same time have a fairly presentable appearance (Figs. 378, 379). They are made of mild rolled steel and are 30 feet long. They are built in two sections, the lower one being a parallel tube, and the upper, 18 feet in length, being tapered to the top. They have buckled steel base plates, 2 feet square, bolted to the bottom, and are fixed upon concrete foundations, the excavation for their reception being also filled in with concrete. They are made in three sizes, the smallest size being 6 inches in diameter at the base, tapered to 2½ inches at the top. These carry arms varying between 2½ feet and 4½ feet in length.



FIGS. 376, 377. Switch for Points and Crossings. Scale, $\frac{1}{18}$.

For the double line, where the rails are at a considerable distance from the footpath, the poles are 7 inches in diameter at the foot, tapered to 3¾ inches at the top, and have arms 7 feet to 10 feet in length. The arms of both sizes of the poles taper from 2⅜ inches to 1½ inch diameter at the end farthest from the pole. It was necessary to provide poles of extra strength as strain-posts at the ends of the several lines; these are 12 inches in diameter at the base, tapering to 5 inches at the top, and are of ½-inch steel. They have attached to them two cast-iron grid frames, 3 feet by 4 feet, one at the base and the other 5 feet higher up, and the intervening space is filled with concrete, which forms, with the pole, a solid block. This type of pole is also fixed in positions originally occupied by lamp-columns at the junction of the main roads, and has been fitted with lamp-fittings in substitution of those removed.

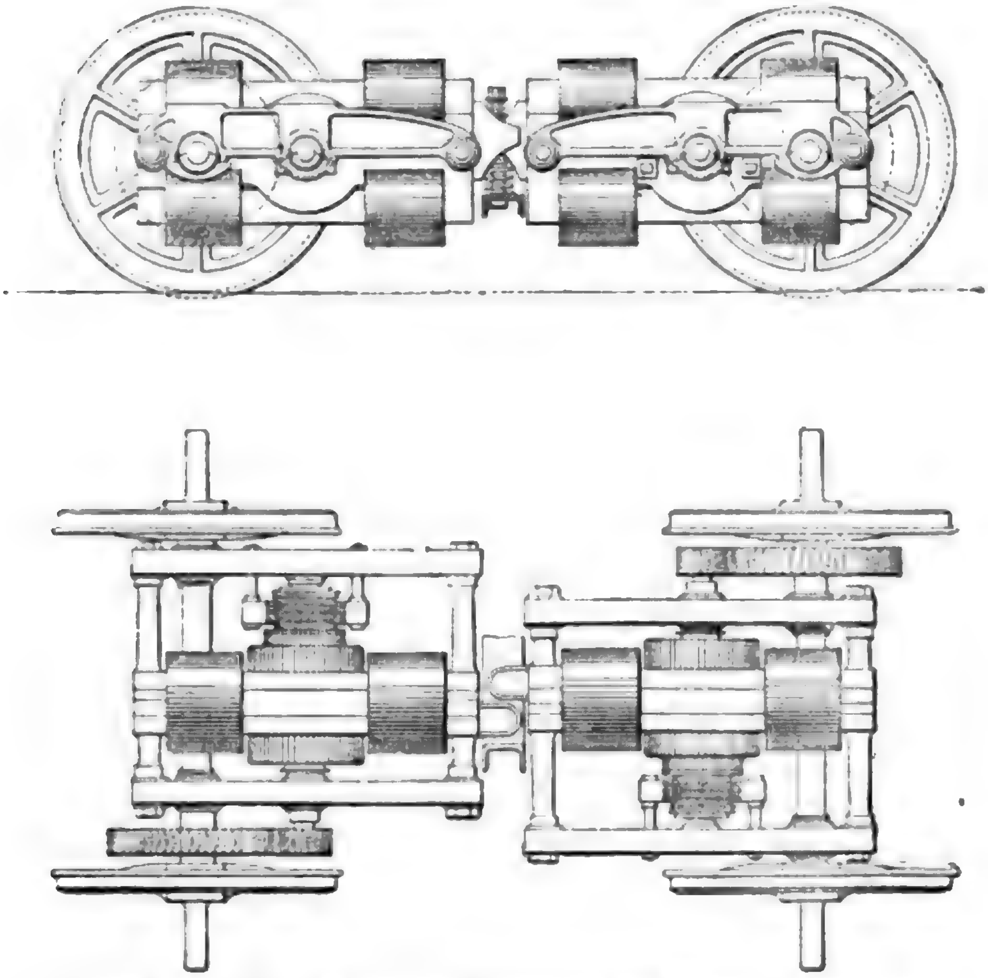


FIGS. 378, 379. Pole for Overhead Wire. Scale, $\frac{1}{48}$.

Sixteen cars have been built, each constructed to carry forty passengers, eighteen inside and twenty-two outside, and weighing, when unloaded, 6 tons 13 cwt. Their principal dimensions are :—

	Ft.	Ins.
Length, including platforms	22	0
,, of body, outside	14	3
Breadth of body, including mouldings . .	5	9
,, inside	5	3½

	Ft.	Ins.
Breadth over roof	5	$10\frac{1}{2}$
Height inside, from the top of the floor to the under side of roof	6	6
Gauge of line	3	6
Wheel base	6	0
Distance between spring-centres	10	0
Diameter of wheels	2	9



FIGS. 380, 381. Motors in Elevation and Plan. Scale, $\frac{1}{16}$.

The body is strongly made and has a bottom frame of channel-bar iron. It is distinct from the motor truck, and is carried upon it by eight springs. The wheels are fitted with two sets of brakes, one to apply on the inside of the wheels, and the other on the outside. They are worked separately by hand-wheels from the platforms at the ends of the cars. The cars are fitted with Nicholson automatic couplings at each end, and four dry sand-boxes, two at each end. These also are worked from either platform.

Each car is fitted with and driven by two series-wound single-reduction motors (Figs. 380, 381). The gearing is of the double helical type, in the ratio of four to one. Each axle has an independent motor, one end being on the axle by two bearings and the other by a spring. There is also at the latter end a spring on the top of the motor, so that at this point it is between springs, the bottom one supporting it and the top one permitting vertical movement. By this method, not only is the pitch-line of the gearing maintained, but the shock to the gearing at starting and stopping is considerably reduced, and the vibration of the motor when running is minimized. The armatures are drum wound. Ordinary arc-lamp carbons ¾ inch in diameter are used for brushes, laid lengthwise along the commutator. The magnets are bi-polar with four limbs.

The cars are fitted with switches in duplicate, one set on each platform. They consist of reversing, driving and motor-switches. Those last mentioned enable the driver to use either motor at will, or both in parallel. The varying resistance of the rheostat in the motor-circuit is controlled by the driving-switch at the will of the driver. As a precaution, and to prevent injury to the motors by careless driving or from other causes, safety-fuses are placed in the motor-circuit. A lightning-arrester is placed in the circuit between the trolley-wire and the driving-switch.

Each car is fitted with a collector, termed a "trolley" (shown in Fig. 382), a peculiar feature of Mr. Dickinson's system. In the American system, it is necessary, in addition to the trolley-wire following the exact curvature of the track, for it to maintain, within a few inches, a constant lateral relation thereto. In Mr. Dickinson's system this is not necessary, and the trolley-wire may run in straight lines and at ever-varying distances laterally from the track, not exceeding, with the trolley-mast in use at present, 26 feet.

The function of the "trolley" is, therefore, to form a continual bridge across the varying horizontal and vertical space between the trolley-wire and the car as it passes along the line. To effect this the apparatus must have a vertical and horizontal radial movement, and this is accomplished by placing upon the roof of the car a fixed socket into which is fitted a spindle (see Figs. 383, 384). On the upper end of this is formed a jaw to receive the base of the trolley-mast. The spindle has a free revolving movement in the socket, the mast is hinged at the top of the spindle, and there has a radial vertical movement controlled by springs attached to the base of the "trolley" at a suitable position on the vertical spindle. On the end of the mast is formed another socket, into which is fitted a trolley wheel carrier, Figs. 385, 386, which has a spindle at its lower extremity fitting into the socket. When working, the trolley-wheel runs on the under side of the trolley-wire, and the vertical pressure to maintain contact is given by the springs on the heel of the trolley-mast. These springs are arranged so as to allow a maximum movement at the trolley-wheel end of the mast with a minimum extension of the springs.

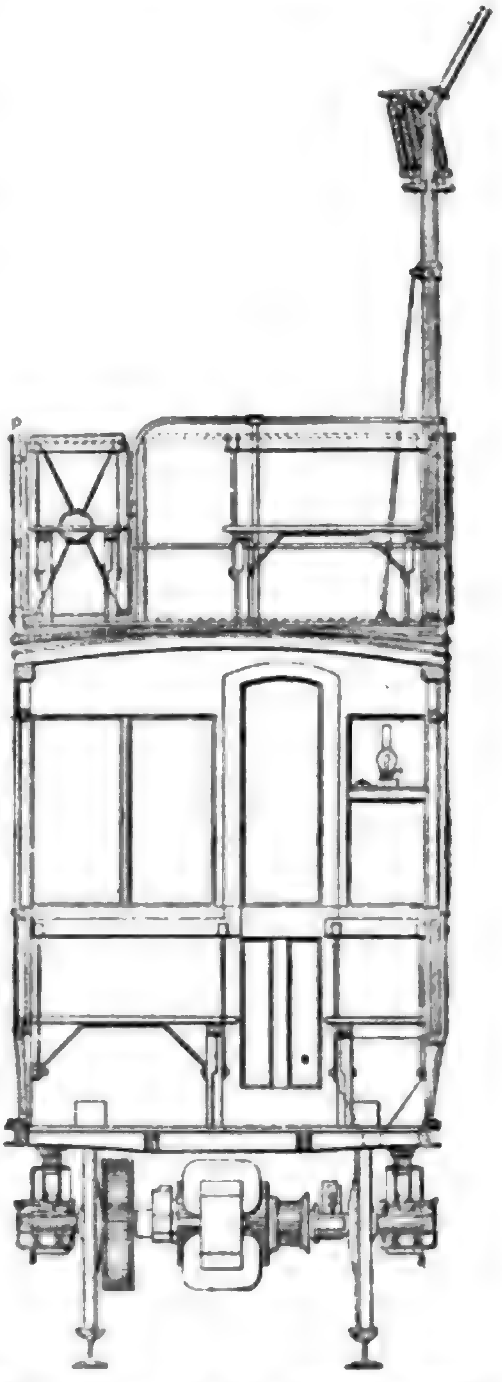
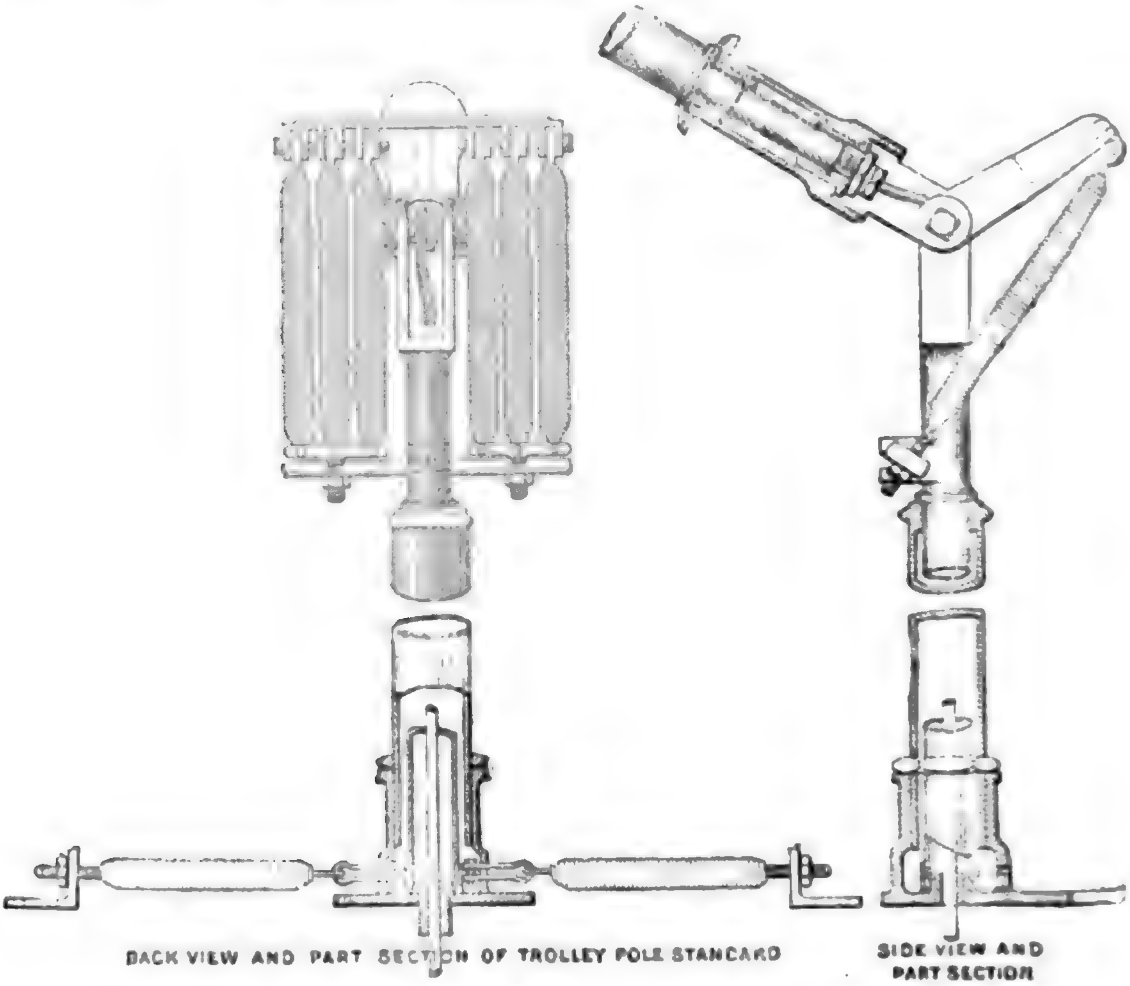


FIG. 382. Diagram showing Trolley and Car. Scale, $\frac{1}{48}$.

The trolley-mast being attached to the radiating spindle, describes a circle with a radius of its own length. The trolley-wheel carrier also having a free revolving movement in its socket on the end of the trolley-mast, the trolley-wheel will, so long as the wire is within the radius swept by the trolley-mast, accommodate itself to and run parallel to the trolley-wire; the trolley-mast will accommodate itself to the varying distances of the wire from the tramway to any position within its reach. This will be better understood by a reference to Fig. 387, which shows diagramatically how the trolley can accommodate itself to the various positions.

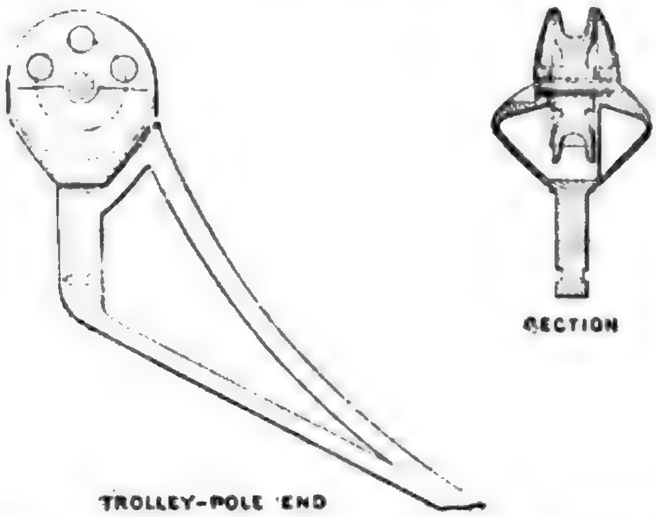

BACK VIEW AND PART SECTION OF TROLLEY POLE STANDARD
SIDE VIEW AND PART SECTION

FIGS. 383, 384. Details of Trolley-pole and Standard. Scale, $\frac{1}{8}$.

By this simple device, the objections entertained by the Walsall Municipal Authorities to the American system have been overcome, as the use of span-wires, pull-over wires, and other objectionable features of that system are thereby largely removed.

The whole of the work was carried out by the Electric Construction Corporation as contractors, to the Author's entire satisfaction.

The electric system of lines was opened for traffic on the 1st January, 1893. From that date to the 28th February, 1894, the cars have run 310,115 miles and have carried 1,920,185 passengers. From the 1st January, 1893, to the 31st December, inclusive, the cars ran 262,692 miles, and carried 1,668,057 passengers, the local authorities, the public, and the directors of the tramway company alike being completely satisfied with the results.



FIGS. 385, 386. Details of Trolley. Scale, $\frac{1}{12}$.

The line is worked by the Electric Construction Corporation under a contract with the Tramways Company, and in dealing with the working cost for purposes of comparison, only those charges where a direct comparison can be made will be dealt with, viz., all those for running and maintenance *minus* traffic charges and maintenance of permanent way. The following statement shows the cost of working several systems of tramway lines in 1893:—

COMPARATIVE STATEMENT OF COST PER CAR-MILE FOR RUNNING AND REPAIRS, 1893.

Charges.	South Staffordshire Tramways Company. Wilkinson Locomotive Steam Engines. Vertical Boilers.	Birmingham Midland Company. Kitson Locomotive Steam Engines.	Dudley and Stourbridge Company. Kitson Locomotive Steam Engines.	Birmingham Central Company.			South Staffordshire. Electric System.
				Kitson, Falcon, and Beyer, Peacock Locomotive Steam Engines.	Electric Accumulator.	Cable.	
Running—	d.	d.	d.	d.	d.	d.	d.
Wages . . .	1·83	1·99	1·45	2·14	3·37	1·54	1·93
Fuel . . .	2·34	1·81	1·94	1·92	1·76	0·60	0·48
Stores . . .	0·33	0·30	—	0·27	0·68	0·19	0·43
Water and Gas	0·28	0·11	0·35	0·18	0·12	0·03	0·08
Sundries . .	—	—	—	0·09	0·17	0·05	0·06
Repairs*— Wages and Materials	2·26	3·62†	4·83	2·19	5·49	1·81	1·08
Total cost per car-mile . .	7·04	7·83	8·57	6·79	11·59	4·22	4·06
Number of miles run	337,423	256,077	112,299	1,225,996	140,993	641,161	262,69

The average cost for fuel on the four lines worked by steam is 2·00d., electric accumulator 1·76d., cable 0·60d., and overhead electric traction 0·48d. per car-mile run.

Hitherto (Mr. Dickinson remarks) it has been most difficult to obtain a direct comparison between electric traction and any other system; but such now is not the case, at any rate so far as the South Staffordshire line is concerned, because the electric cars are running upon lines previously worked by steam.

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* The items referring to steam traction include repairs of every description; those to electric accumulator traction include stationary engines and boilers, dynamos, motors, batteries, switches and all repairs pertaining to an electric installation; to cable traction—stationary engines and boilers, cable, pulleys in road, cars and all repairs incidental thereto; to overhead electric traction—stationary engines and boilers, dynamos, motors, poles, feeders, overhead wire, cars and all other repairs in connection with an electric system.

† This item includes an amount taken from depreciation fund.

When designing the system, Mr. Dickinson was in doubt as to the amount of steam-engine power to provide in the generating-station per car on the lines, and how to arrange its subdivision, as the number of cars upon the line at different times would vary considerably. However, he ultimately decided to split the power into three elements, so as to be able to reduce it to suit the number of cars running upon the line at any given time. He was prepared, from his experience in the working of the cable-line in Birmingham, for a considerable variation in the load; but he certainly never anticipated that its range would be so great in so

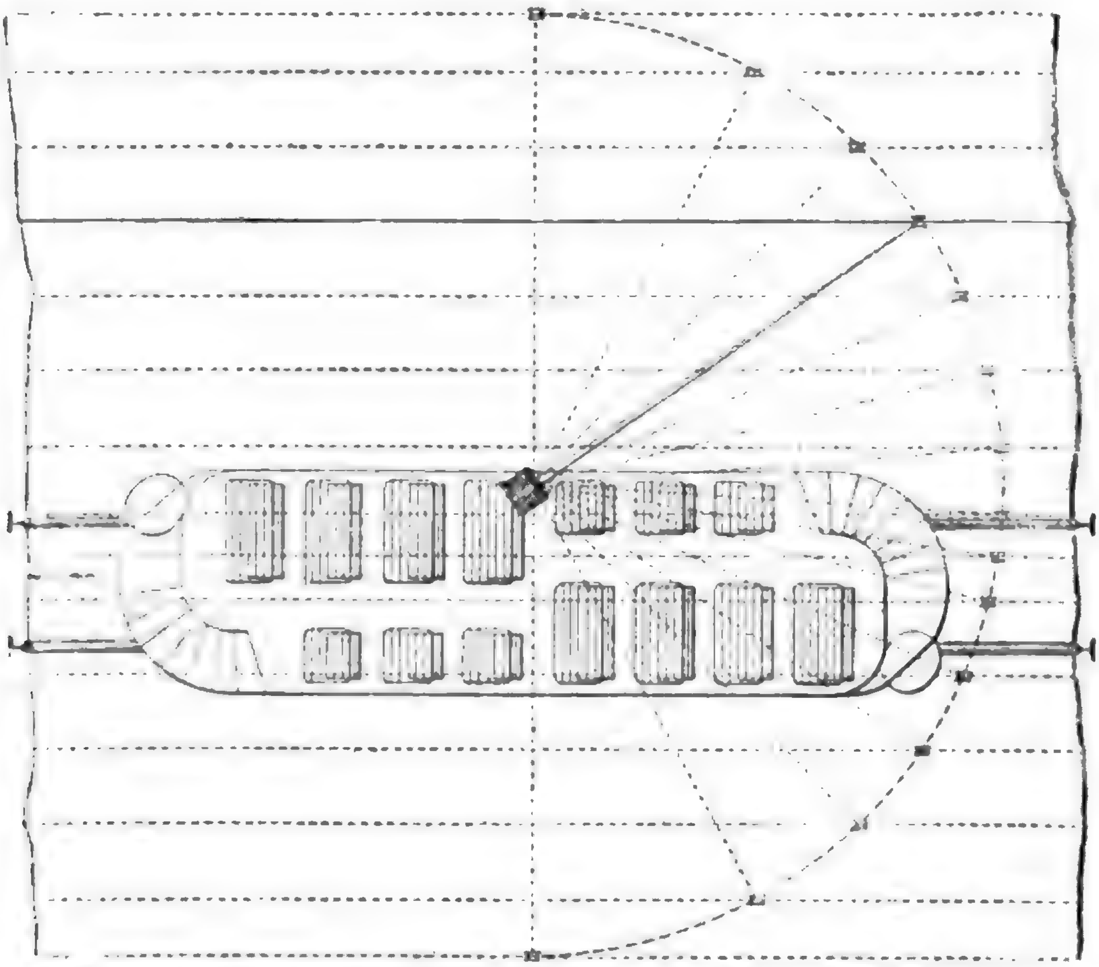

FIG. 387. Plan of Car, showing various positions of Trolley-pole. Scale, $\frac{1}{60}$.

short a time as he has found to be the case. With sixteen cars on the line, the output has been found to vary as much as 233 E.H.P. in the space of five seconds, and with eleven cars upon the road as much as 202 E.H.P., in the same period.

Taking into account even the extraordinary fluctuations caused during holiday times, the cost per car-mile for fuel is below that of cable-traction; and in this comparison it is well to bear in mind that the power on the cable route is distributed over only three miles of route with double the number of cars running, as against eight miles of route on the electrical section.

Mr. Dickinson states that he has had a motor that had been running for fourteen months taken from a car and tested with a "Prony brake," when its mechanical efficiency was found to be 78 per cent.—a most satisfactory result. At the same time he tested the torque of the armature with a current of 48 amperes taken from the trolley-wire under normal conditions, and found this would raise a weight of 141 lbs. at the end of a lever 7 ft. long. This is equal to a torsional force of 1,692 lbs. weight on the armature. Testing with a dynamometer the amount of pull to be obtained on the drawbar, with all the resistance cut out and both motors in circuit, he found it was 1 ton 7 cwt. He then tested a Wilkinson engine at a boiler-pressure of 150 lbs., with cylinders 7⅝ in. diameter geared 1¾ to 1, and this gave exactly the same pull.

After running for fourteen months, it is satisfactory to find that it is scarcely possible to measure the wear and tear upon the trolley-wire.

CHAPTER IX.

THE NEVERSINK MOUNTAIN ELECTRIC RAILROAD.

THIS road, which was constructed in 1890, is of special interest as the pioneer electric railway worked by turbines.[*]

Neversink mountain, with its electric railroad, lies to the east of the city of Reading, in Berks county, Pennsylvania. In the accompanying illustration (Fig. 388) not only Neversink mountain and its railroad, but the contiguous railroad lines, are shown. The Neversink line, encircling the mountain, rises by varying grades from the streets of Reading up the foot slopes, and thence along the mountain sides to the summit.

The route usually taken by the cars is from Ninth and Penn Streets to the White House (Fig. 388), thence by the mountain loop over the summit down to Klapperthal Park and the terminal, a distance of 6·99 miles. On the return the cars go over the same route as far as the Upper Junction, thence down the Short Line, to the main line, at the Lower Junction, past the White House and down to Ninth and Penn Streets, a distance of 4·07 miles, making the total length of the round trip 11·06 miles. The schedule time of the round trip is about one hour and 20 minutes,

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[*] See *Test of the Neversink Mountain Electric Road*, by Hermann S. Hering and William S. Aldrich, of Johns-Hopkins University, U.S.A., from which publication the particulars and illustrations given in this chapter are taken.

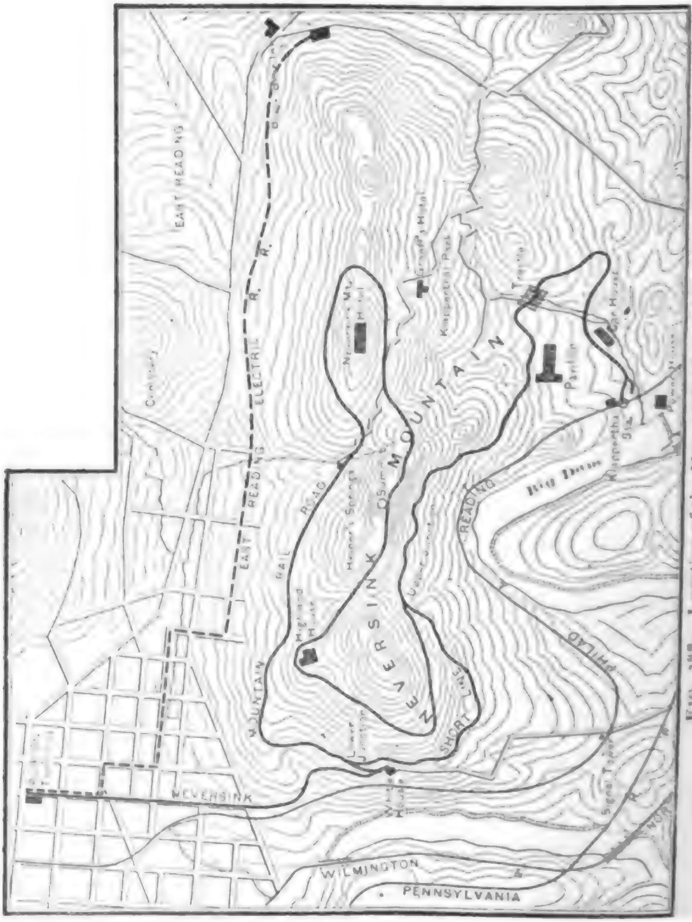
EAST READING
ELECTRIC R. R.
EAST READING
RAIL ROAD
MOUNTAIN
NEVERSINK MOUNTAIN
READING
PHILAD
SHORT LINE
NEVERSINK
WILMINGTON
PENNSYLVANIA
Big Dam
Highland House
Kuechler's Park
Pavilion
Klapperthal Glen
Signal Tower

Fig. 358. Location of the Neversink Mountain Railroad.

including all stops, though it can be made in one hour without difficulty.

Figs. 389, 390 (Plate X.), show a plan, elevation, and right-side view of the turbine plant (details of the transmission machinery will be given presently); and Fig. 391 (Plate XI.) the arrangement of the wiring.

During the summer of 1891 the usual schedule for week-days required a car to leave the terminus every half-hour, necessitating three cars on the road, and for Sundays every 20 minutes, requiring four cars (or preferably five) for heavy travel. The schedule and route are so arranged that about half the cars are going up-grade while the others are going down-grade. This arrangement makes a very economical distribution of power along the road, preventing, as far as possible, excessively large currents, such as would be required if all the cars were on the up-grade at the same time. The speed of the cars over the mountain is from 9 to 15 miles per hour.

The cars make from eight to ten trips a day usual running time, averaging from 88 to 111 miles per car per day. The seating capacity of each car is 44 passengers, but in heavy travel they have carried as many as 170 passengers per car. During six weeks, in the summer of 1891, 40,000 passengers were carried, reaching a maximum of 3,000 per day with five cars on the road at one time. The company expected, with its enlarged equipment, to carry 250,000 passengers over the road during the summer months of 1892.

Owing to the uncertain limit of the probable maximum load in electric traction work, it is necessary to operate the turbines as prime movers at a point much below their known capacity at full gate, because of their inability to develop any greater power than that represented at full gate and normal speed. This is an analogous case to that of the series motor. Steam-engines, on the contrary, as prime movers in electric traction work, are capable of far exceeding their known rated capacity to meet the large and sudden loads which are on only for a short time, by reason of the possibilities bound up in the expansive working of the steam, especially in the multiple-cylinder type.

The incompressible nature of the working fluid employed in turbines as prime movers prevents their exceeding the output, as determined by the dimensions of the machine, while the elastic nature of the working fluid in steam-engines enables them to exceed their rated dimensional capacity for extraordinary demands. Consequently, for electric traction work, turbines must be operated considerably below their maximum capacity, or at part gate during the average maximum loads of the day, so that they will be able to meet the extraordinary loads that will be sure to arise at unexpected times. As it will be necessary for constructing engineers to select turbines that will be efficient at part gate, and particularly at the ordinary maximum of half gate, it becomes the aim of turbine builders to design wheels for traction purposes to meet these particular requirements.

Subjoined are particulars of the power employed :—

WATER SUPPLY.

Flume, diameter in feet	10
Nominal head of water, in feet	18

HERCULES TURBINES.

Diameter, in inches	45
Effective area of guide opening, square inches	623
Rated speed, revolutions per minute	110

COMMERCIAL RATED PERFORMANCE, FULL GATE.

Rated discharge of each turbine, cubic feet per minute	8,833
Rated efficiency, full gate and rated speed, in per cent.	80
Rated horse-power, at this efficiency, each turbine	240

ACTUAL PERFORMANCE AT FULL GATE.*

Actual discharge, each turbine, cubic feet per minute	8,588
Actual efficiency, 110 revolutions, in per cent.	80·7
Maximum dynamometric horse-power, each turbine	210

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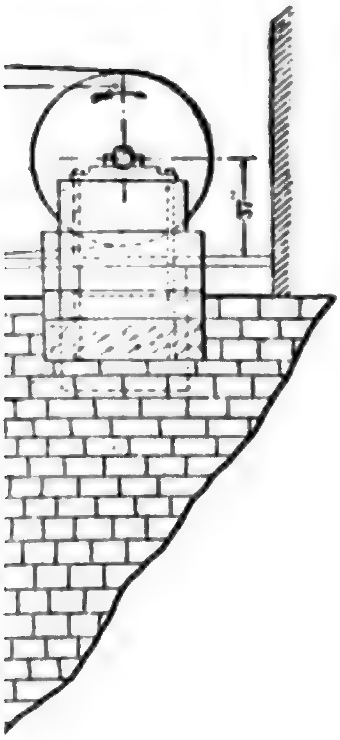
* The data relating to the actual performance of the turbines were obtained from the results of the test of the Hercules turbine made by the Holyoke Water Power Company, and kindly furnished to Messrs. Hering and Aldrich by that company.

PLATE X.



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ACTUAL PERFORMANCE, ABOUT HALF GATE.

Mean position of speed gate, being the proportional part of the full opening of the speed gate, in per cent.	53·3
Actual discharge at critical speed for this gate, cubic feet per minute	5,528
Efficiency, critical speed 100, in per cent	75·37
Efficiency, rated speed of 110	74·4
Actual dynamometric horse-power of each turbine at the critical speed of 100 revolutions per minute	132·5
Actual dynamometric horse-power of each turbine at the rated speed of 110 revolutions per minute	128·5

The jackshaft, over the turbines, is driven from the vertical turbine shaft, through bevel gear, and drives the countershaft through the main belt. Each dynamo pulley is belted to the friction clutch pulley on the countershaft.

The essential details of transmission machinery are shown in the following tables:—

GEARED AND BELTED CONNECTIONS.

Number of teeth on mortised crown gear, vertical shaft	49
Number of teeth on jack gear, horizontal shaft	31
Diameter of main driving pulley, in inches	108
Diameter of main driving pulley, on countershaft	66
Diameter of driving pulleys (friction clutch)	60
Diameter of pulleys of dynamos	26
Main driving belt, extra double, width in inches	45
Dynamo belts, double, in inches	15
Length of main driving belt, in feet	83

RATED SPEEDS.

Turbine shaft (vertical), revolutions per minute	110
Jackshaft over turbines	175
Countershaft	286
Dynamos	650
Speed of main driving belt, feet per minute	4,950
Speed of dynamo belts	4,300

DISTANCES BETWEEN SHAFT CENTRE LINES.

Between the vertical shafts of the turbines, in feet	16·5
Between the jackshaft and countershaft	30
Between the countershaft and dynamos	20

The transmission of the turbine power through the mortise crown and jack gear leads to a loss. On the other hand, the two belted connections to an intermediate countershaft result in the usual loss of power experienced in stations driven by steam-engines. These losses are grouped as transmission machinery friction in the summary of the test.

The additional loss through bevel gearing is inherent in this method of transmitting the power from the prime mover shaft to the main driving shaft. The efficiency of the transmission machinery, however, is the same as in steam-engine plants, when the turbine shaft (like the crankshaft) is the main driving one. Similarly, the driving of the dynamos by one belt from the turbine shaft is but an intermediate step for driving them directly coupled, as has been projected at the Niagara plant, which is, of course, the most efficient method.

As at present equipped, there are two Edison compound-wound 100-kilowatt railway generators. Each dynamo has complete switchboard connections, field resistances, ammeters, fuses, and switches, and either or both may be connected with the line circuit, and be driven by either or both turbines. Lightning arresters are carefully placed in each feeder circuit.

The results of the test show that large variable loads on the line cause great speed variations in the turbines, as here governed and coupled, resulting in considerable drop in the voltage at one time and considerable rise at another. Even with the best method of governing turbines now in use these voltage variations will be great—indicating that the dynamos for such plants should be very much over compounded.

From Ninth and Penn Streets to the city limits the line construction is of the ordinary overhead type, with wooden side poles and span wires. From this point over the mountain the construction is of the side-bracket type, with plain undressed wooden poles and iron pipe brackets. The poles are placed 100 feet apart, but this is often varied on account of the great variations in the curvature of the road at many points, frequently necessitating pull-offs and anchor guys.

The ground return within the city limits is made by connecting the double-bonded flat rails to a No. 4 B. & S. copper wire imbedded between the rails. On the mountain the T-rails are double-bonded throughout and cross-connected at two points, as shown in the wiring diagram, Fig. 391 (Plate XI.). These cross-connections are made with No. 4 and No. 00 B. & S. wire. The same two sizes of grounds are used from a point on the line near the pavilion to the power-house, while a third ground, No. 000 B. & S., leads from a point near the car-house to the power-house, where these grounds are connected to the dynamo.

Four feeders are run from the power-house: a No. 000 B. & S. to the White House; a No. 00 B. & S. to the Highland House; a No. 000 B. &. S. to a point near Heiner's Springs on the north side of the mountain; and a No. 1 B. & S. to a point near No. 13 turnout. Mains of Nos. 4, 1, 0, and 000 B. & S. are run along the entire route, except from the Highland House to the No. 8 turnout, in which the No. 00 feeder is used for both purposes. The general distribution of the mains and feeders, and their respective sizes, are shown in the wiring diagram, Fig. 391.

The line resistance was determined at various points by taking simultaneous readings at the power-house and on the car, and making the computations from the current and drop of potential thus obtained.

Mean resistance over entire line, in ohms	0·48
Maximum resistance on the line, „	0·84
Minimum „ „ „	0·30
Mean drop of voltage, per cent. (about)	6·0
Maximum drop of voltage, per cent. (normal current) . .	10·5
Minimum „ „ „ „ . .	3·9
Mean line efficiency, per cent. (about)	94·0

The track construction over the mountain is of the railroad type, with 56-pound steel T-rails, set to standard gauge of 4 feet 8½ inches, with standard tie system of 26-inch spacing, but within the city limits ordinary flat tram-rails are used. The road is ballasted with two feet of crushed stone, and has withstood the most severe storms, with no wash-outs.

Road data are given as follows :—

TRACK.

	Feet.	Miles.
Length of road, including short line	41,116	7·787
Length of straight track (41·5 per cent. of total)	17,066	3·232
Longest stretch of straight track	2,000	0·379
Average length of straight portions of track	304·7	0·058

CURVES.

Eight 35 to 40 degree curves, mean length	278 feet.
Two 40 degree curves on a 5 per cent. grade.	
The longest is a 35 degree curve, 3·5 per cent. grade, length	525 ,,
Ten 20 to 30 degree curves, mean length	377 ,,
The longest is a 25 degree curve, near Highland House, length	654 ,,
Forty-six 10 to 20 degree curves, mean length	251 ,,
The longest is a 20 degree curve, 3·64 per cent. grade, length	690 ,,
The steepest is a 20 degree curve, 6·4 per cent. grade, length	251 ,,
Eighteen 0 to 10 degree curves, mean length	378 ,,
The longest is a 1 degree 40 minute curve, 3·94 per cent. grade, length	1,047 ,,
The steepest is an 8 degree curve, 4 per cent. grade, length	460 ,,
The average curvature (excluding straight track) of 82 curves	17·35 deg.

GRADES.

Sixteen grades, varying from 1 to 6·4 per cent.	Feet.	Miles.
The shortest grade is a 1·00 per cent.	400	0·07
The longest grade is the 3·64 per cent.	11,575	2·19
The steepest grade is the 6·4 per cent.	925	0·18
Mean ascending grade, round trip, 3·74 per cent.		
Total length of ascending grades	27,805	5·26
Total car-lift, round trip	1,040·1	

Mean descending grade, round trip, 3·45 per cent.	Feet.	Miles.
Total length of descending grades . . .	30,170	5·72
Total car-drop, round trip	1,040·1	

Mean grade, Ninth and Penn to Klapperthal, *viâ* Short Line, 3·71 per cent.

Mean grade Ninth and Penn to Klapperthal, *viâ* Neversink Mountain Hotel, 3·475 per cent.

Mean grade of the entire road, 3·53 per cent.

The following table gives the speed of regular passenger cars on the usual round trip :—

	Including Stops.	Excluding Stops.
Ninth and Penn to Klapperthal (over the mountain)	9·8	10.9
Klapperthal to Ninth and Penn (*viâ* Short Line)	8·1	10
Round trip, Ninth and Penn and return	8·75	10·5

RUNNING TIME.

Ninth and Penn to Klapperthal (over the mountain)	42¾ min.	38½ min.
Klapperthal to Ninth and Penn (*viâ* Short Line)	30¼ min.	24½ min.
Stop at Klapperthal	4 min.	
Round trip, Ninth and Penn and return	1 hr. 17 min.	1 hr. 3 min.

Stops for few passengers, require from ¼ to ½ minute.
Stops at regular stations, require from ½ to 1½ minutes.
Stops due to connections in junctions are about 4 minutes.
Stops at Klapperthal terminal are about 4 minutes.

In the subjoined Table is given a summary of power distribution and efficiencies, made with special test car No. 4, on the two principal grades, 3·64 per cent. and 3·94 per cent., no other car being on the road at that time. The mean speed on the grades is exclusive of stops. Weight of car alone, 22,000 pounds; with load during test, 22,500 pounds.

Grade on which reading is taken.	3·64 per cent.		34·0 per cent.	
Time and time interval on grade.	11-37-30	11-31-45 to 11-39-30	12-8-0.	12-0-0 to 12-1[illegible]-0
Conditions.	Steady.	Mean.	Steady.	Mean.
Speed of turbine shaft	97·0	98·5	97·0	101·5
Gate opening, No. 1 turbine	31·7	30·6	31·0	30·2
,, No. 2 turbine (fixed gate)	17·4	17·4	17·4	17·4
Speed of car, miles per hour	12·4	11·43	11·4	10·02
POWER DELIVERED.				
Hydraulic H.P. delivered to turbines	190·0	187·0	188·2	184·2
Turbine H.P. delivered to transmission machinery	93·2	88·7	01·4	86·0
H.P. delivered to dynamo	56·1	53·15	55·1	51·9
E.H.P. delivered to line	48·5	45·9	47·6	44·7
E.H.P. delivered to car motors	46·0	43·1	44·8	42·3
H.P. delivered at car axles	34·50	31·92	33·7	31·78
POWER LOST.				
Turbine friction H.P.	96·8	98·3	96·8	98·2
Trans. machinery friction H.P.	37·1	35·55	36·3	34·1
Dynamo losses	7·6	7·25	7·5	7·2
Line losses...	2·5	2·8	2·8	2·4
Car motor, gearing and axle losses	11·5	11·18	11·1	10·52
Total losses, Hydraulic H.P. to car axle H.P.	155·5	155·08	154·5	152·42
H.P. available at car axle	34·5	31·92	33·7	31·78
Total Hydraulic H.P. delivered	190·0	187·0	188·2	184·2
PROPORTIONAL PARTS OF FULL LOAD.				
Hydraulic load, per cent. of full hydraulic H.P....	36·2	35·7	35·9	35·2
Turbine load, per cent. of full turbine H.P. ...	22·5	21·4	22·1	20·6
Dynamo load, per cent. of full dynamo output ...	30·2	34·2	35·5	33·3
Motor load, per cent. of full motor output... ...	71·5	08·8	71·5	67·7
PERCENTAGE DISTRIBUTION.				
Turbine friction, per cent. loss	·509	·526	·514	·533
Trans. machinery friction	·195	·187	·104	·185
Dynamo	·040	·038	·040	·039
Line...	·013	·015	·014	·013
Car motor, gearing and axle losses	·061	·063	·059	·057
Available power at car axle	·182	·171	·179	·173
Total hydraulic power	1·000	1·000	1·000	1·000
SUMMARY OF EFFICIENCIES.				
Efficiency of No. 1 turbine	58·7	57·4	58·0	55·8
,, No. 2 turbine	33·8	32·9	34·0	31·4
,, coupled turbines...	49·1	47·4	48·5	46·7
,, trans. machinery...	60·2	59·0	60·3	60·4
,, No. 1 dynamo	86·5	86·3	86·4	86·1
,, line mean, for given grade	94·8	94·0	94·1	94·8
,, car motors, from terminals to car axle	75·0	74·2	75·2	75·1
Efficiency from dynamo terminals to car axle ...	71·2	69·7	70·8	71·2
,, Hydraulic H.P. to line H.P. ...	25·5	24·5	25·3	24·2
,, Hydraulic H.P. to car axle H.P....	18·2	17·1	17·9	17·2

PART VII.

SUPPLEMENTARY CHAPTERS.

CHAPTER I.

OIL MOTOR.

THE Connelly oil motor has been at work on the Greenwich and the Croydon Tramways since the beginning of 1893. "The engine, which is fixed in a small car, has a pair of overhead cylinders driving a crank-shaft, and is capable of developing 12-horse power on the brake. The mineral oil is stored in a cylindrical tank placed within another cylinder and carried above the engine. The engine-cylinders are kept cool by means of water-jackets, and the water used for this purpose is pumped up to the oil tank and circulates around it in the annular space between it and the outer cylinder. On leaving the jackets of the engine-cylinders the temperature of the water is about 110 deg. Fahrenheit, and this is sufficient to heat up the oil to a point at which it gives off the vapour utilised in driving the engine. After having imparted heat to the oil, the water flows down to a nest of tubes placed under the car and exposed to the atmosphere. In flowing through the tubes the water becomes cooled down sufficiently to be used for cooling the engine cylinders, to which it is pumped up. The water, in fact, is kept in constant circulation, first cooling the engine cylinders, then warming the oil, and afterwards being cooled down for use over and over again. The ignition of the charge of gas in the engine-cylinder is effected by electricity, there being a small dynamo in the car in which the engine is mounted. This dynamo is driven by a strap from the engine, and the current is stored in an accumulator used for igniting the charge, as well as for lighting the car at night. The gearing, by means of which this locomotive is driven and the speed regulated, is very ingenious. As the speed of a gas-engine cannot be varied like that of a steam-engine, it has to be run at a nearly uniform rate, the speed being controlled by the transmitting gearing. This consists of an iron disc, 30 inches in diameter, which is mounted vertically on the end of the crank-shaft. On a vertical shaft set parallel with the disc is a friction-pulley, 12 inches in diameter, and capable of being moved up and down on the shaft. When, however, it is revolved by contact with the disc, the shaft on which it is mounted revolves with it and transmits motion through gearing to the driving wheels. The pulley can be moved up and down its shaft, farther from or nearer to the shaft, at the will of the driver. At starting the pulley is brought into contact with the disc near its centre, which gives a slow motion with great power. For increasing the speed the pulley is moved up its shaft, and consequently approaches the edge of the disc, by which means it is revolved more rapidly. When it is desired to slacken speed, or to stop the car, the friction-pulley, still in contact with the disc, is moved down to near the centre, at which point it can be slightly removed from the face of the disc. As the engine cannot be reversed, clutch gearing is employed, and is placed under the car, and at the end of each journey it is set to drive the locomotive forwards or in the opposite direction as may be required. In this engine the products of combustion pass away noiselessly and without smell, neither is there any escape of the vapour of the oil, the consumption of which is very low. From a return of seven days' working—14 hours a day—it appears that 350 trips were made, covering 507·85 miles, and carrying 4,182 passengers, with a total consumption of 70 gallons of oil. On recently making a few runs with this engine we found it to work most satisfactorily, taking gradients and sharp curves well, maintaining the Board of

Trade regulation speed of eight miles an hour easily, and being evidently capable of a far higher speed." *

Professor W. C. Unwin reports that the Connelly oil motor, running daily on the Croydon Tramway, takes an ordinary tramcar for forty passengers over the line, having gradients of 1 in 20, at an average speed, including stoppages, of 4·65 miles per hour. The car is completely under control, and starts and stops on gradients without difficulty or shock.

Mr. John S. Comrie reports the result of one week's test-trials at Croydon, in December, 1893, "during which the motor travelled 291·5 car-miles, carried 1,465 passengers, and consumed 48½ gallons of oil, the time on duty being 64·916 hours, and the rate of speed 4·49 miles per hour, the speed being regulated by the horse traffic. If required, the motor can be geared to run 16 miles an hour.

"The small number of miles run and the passengers carried in a week arises from the motor only having been on duty in the afternoons and evenings to suit the requirements of the Croydon Tramways Company.

"The route was from Poplar Walk to the Thornton Heath terminus of the Croydon Tramways, a portion of the line affording a very varied and severe test, as, in addition to loops or passing places inseparable from a single line, there are several considerable curves and gradients, the most severe being one of 5 per cent. The motor, with car and load, accomplished these satisfactorily, on one occasion ascending the greatest gradient with a car weighing over 2½ tons and containing 46 passengers, and at all times was under perfect control as regards shunting, starting and stopping, the last two operations being performed in 15 seconds, without shock to passengers.

"With regard to the special feature of the motor which distinguishes it from all those hitherto suggested, the gear transmitting the power of the engine to the wheels works excellently, is extremely ingenious, and perfectly solves the hitherto impossible problem of adjusting the invariable speed of a gas or oil engine

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* *The Times*, March 20th, 1893.

to the varying speed requisite in a tramcar, and gives simultaneously the maximum of power and the minimum of speed essential to the satisfactory start.

"The consumption of oil is ·166 gallon per mile, or ·747 gallon per hour, and placed in a locked reservoir under my supervision, and the route being personally measured, and the hours of duty. My investigation proves the capacity of the motor to perform the ordinary daily tramway duty of 72 miles per day without having to re-enter the depôt to be re-charged with oil, as its reservoir is capable of containing not less than 14 gallons.

"The above results having been obtained on a single line, allowing only of a speed of less than 4½ miles an hour, it may be fairly deduced that those attained on a double line, where a speed of 6 miles an hour would be practicable, should be considerably better. The wear of the face-plate abutting on transmission gear was so slight as to be scarcely appreciable."

CHAPTER II.

COMPRESSED GAS MOTOR.

A MOTOR, driven by compressed coal-gas, has lately been introduced by the Traction Syndicate, Limited, as an economical means of tram-car propulsion. A public trial of the motor on the line of the Croydon and Thornton Heath Tramways Company is reported in the public press, the car and its motor being now, as a result of the trial, in regular work on the line referred to.*

The motor is placed under the tram-car together with three cylindrical gas-holders. The machinery occupies the space under one of the seats of the car, whilst one of the gas-holders is carried under the opposite seat, the other two holders being placed transversely under the car-framing. The three reservoirs will hold a sufficient supply of gas to serve for an eight-mile run.

The car is described as "not noticeably different from a horse-car; it runs quietly and easily, emitting neither smoke nor steam, and is quite under control. Inside passengers can hear a slight rumble of machinery, and perceive a trifling vibration, but practically there is nothing to detract from their comfort. Neither they nor bystanders in the street can perceive any machinery whatever, for the engine and gearing are entirely enclosed, the motor lying under one seat, and the wheels and clutches under the floor of the car."

The car is about 18 feet long, and, with the machinery, weighs 5½ tons. It is driven from either end, there being a starting and stopping lever and a hand-brake on each platform. The motor, which is of the Otto type, and is specially constructed for tramway work, has a slow and a quick speed, although the latter cannot exceed the maximum of eight miles allowed by the Board of Trade. The ignition of the charge in the motor cylinders is effected by electricity, and the cylinders exhaust into a condenser, so that it is cleansed, no smell arises, and no public nuisance is created by the escape of the products of combustion into the atmosphere.

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* For reports of the trial, see *Times* of 20th June, 1893, and *Engineering* of 22nd June, 1893.

The driver stands on the end platform, with the usual brake handle beside him, and in front of him a lever which operates the clutches controlling the gearing. With the lever vertical the engine is out of engagement with the axles; when the lever is placed to one side or the other, the slow or the fast gear is in engagement.

The motor has two cylinders, placed face to face at opposite sides of the crank-shaft, and both driving on to one crank. At one end of the shaft, that nearest the side of the car, is a fly-wheel, and at the other end a pinion, gearing into a wheel on the first motion shaft which lies under the floor of the car. On this shaft are two pinions, either of which can be made to drive a second motion shaft, the large pinion giving a speed of eight miles an hour to the car, and the small pinion half that speed.

Each of these pinions is furnished with a friction clutch, consisting of two discs with a ring of beechwood between them. One disc is set up towards the other by means of bell-cranks and spring toggle arms pivoted to a sliding collar, the arrangement being such that when the clutch is in engagement the pressure of the arms is about at right angles to the shaft, and there is no end thrust on the sliding collar. The second motion shaft is geared to the axles by pitch chains. For driving in the opposite direction, the rotation of the first motion shaft is reversed by means of intermediate wheels and claw clutches.

Although with gas-driven car the engine must not be stopped *en route*, but must run constantly, whatever the car may do, it is susceptible of a certain amount of regulation. When the work is light, the governor cuts off the gas supply to one cylinder entirely, the other doing all the work. The governor is loaded by a spring on the spindle, and also by weights on an external lever, and these weights can be lifted by the same handle that operates the clutches. By this means the speed of the engine is reduced by some 50 per cent. when the car is standing, and, further, the gas admission is delayed till half-stroke, with the result that the explosion is rendered much more gentle, and less likely to give rise to vibration.

The charging-station is at the depôt of the Croydon and Thornton Heath Tramways Company, at Thornton Heath, where an 8-horse power Otto gas engine drives a compressor. By this latter the gas, which is taken from the gas company's mains, is pumped into a steel cylindrical receiver 25 feet in length and 4 feet in diameter, at a final pressure of ten atmospheres as a maximum, or 150 lbs. per square inch. This plant is equal to the supply of five tram-cars, the number which it is intended to place on the line for the present. Five more are to be added in due course, when another compressor and receiver will be put down and will be driven by the present engine, which is of sufficient power for the purpose. From the receiver a pipe is laid down to the tram-car charging-point, the cylinders on the car being charged in the same way as those of railway carriages are charged with gas for lighting purposes. The pressure in the tramcar cylinders is about eight atmospheres, or 120 lbs. per square inch, at starting.

It carries 28 passengers in all, and makes a very fair speed, the limit allowed by the Board of Trade being 8 miles per hour. With the slow gear it will readily mount an incline near Thornton Heath station of 1 in 23, with a short piece of 1 in 16, and in coming down it can be stopped by the brakes in its own length. It also goes round a curve of 35 feet radius on a 1 in 27 grade. Its weight, filled with passengers, is 5½ tons. The first cost of the car, with its motor, it is stated, is not greatly different from that of a horse-car with its 11 horses. For gas it costs 1d. per mile, against 3½d. per mile for fodder and bedding for horses. So that it starts with an advantage of 2½d. per mile.

CHAPTER III.

SUMMARY REMARKS ON MECHANICAL MOTORS.

MECHANICAL motors in considerable variety have, in addition to horses, been passed in review:—compressed-air locomotives, steam locomotives, fireless locomotives, cables, electric locomotives. In addition to these may be noted oil motors, and compressed-gas motors, of recent introduction. The practice of the Birmingham Central Tramways, on which four systems of traction have been in work for some years, affords a means of making direct comparisons under like general conditions of gradients, &c. The receipts and expenses, shown, page 85, averaged, for the three years ending June 30, 1891, 1892, and 1893, as follows:—

Three years ending June 30, 1893.	Average Receipts er mile run.	Average Expenses per mile run.
	Pence.	Pence.
Steam	15·87	11·41
Horse	11·05	9·89
Cable	12·57	6·28
Electric	15·09	13·95

Here the cable system of traction is conspicuously the lowest in working cost: 6·28 pence per mile, followed by 9·89 pence for horse-power, 11·41 pence for steam-power, and 13·95 pence for electric power by the accumulator, which is more than twice the cost for cable-power.

Carefully prepared comparative estimates have been drawn up by Mr. C. B. Fairchild,* showing the capital and working costs of cable roads and electric roads. The estimates are for three miles of double-track, with the power station near the centre of the line. Trains consisting of a motor car in one case and a grip car in the other, with a trailer, run on a four-minute headway, requiring 15 trains. This, of course, gives the same car mileage as 30 single cars on a two-minute headway would run. The average speed calculated on is about 6 miles an hour, the maximum being 8, and the cars run 19½ hours a day. Summaries of the estimates are as follows:—

ELECTRIC.—ROAD COST.

	Dollars.
Road bed	163,822·80
Special street construction	1,811·50
Overhead construction	16,361·40
Special overhead construction	418·00
Power-house and plant	134,750·00
Rolling stock and equipment	74,625·00
Car barn and repair shops	40,000·00
Auxiliary appliances	8,650·00
Engineering, legal, and miscellaneous, at $5,000 per mile	15,000·00
Total for three miles double track	455,438·70

CABLE.—ROAD COST.

	Dollars.
Power-house and plant	102,000
General street construction	304,396
Special street construction	28,500
Rolling stock	33,000
Car barn and repair shops	37,500
Auxiliary appliances	6,050
Engineering, legal, and miscellaneous, at $4,000 per mile	12,000
Total for three miles double track	523,446

Putting the figures into British money roughly, it will be seen that the electric road is estimated to cost £91,088, against

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* See *Street Railways: their Construction, Operation, and Maintenance.*

£104,689 for the cable. This is £30,363 per mile double-track for the former, and £34,896 for the latter.

The cost of constructing a longer electric line would be in direct proportion to the number of miles, and the cost for power plant will increase according to the number of cars, but the cost of real estate, power and car houses, will remain the same for a considerable increase of mileage or traffic. Similarly, for the cable, the cost of street construction would be in proportion to the length of the line, but one power-house, if properly located, and one main vault, will answer for a six-mile line. Under favourable conditions one station will serve for operating half-a-dozen or more lines. Besides that, the cost of additional cable cars and engine-power would be a mere trifle compared to that of the additional electric cars, dynamos, and engine-power.

Mr. Fairchild's estimates of the working costs per day for an electric line and a cable line, constructed according to the foregoing estimates, are as follows :--

ELECTRIC ROAD.—WORKING COST PER DAY.

	Dols.
Twelve tons of coal at $2·50	30
Water, oil, and grease for engines, generators, cars, and motors	10
Depreciation of plant and rolling stock . . .	38
Sixty-six motor-men and conductors at $2 . . .	132
Engineers, firemen, and dynamo tenders . . .	25
Car-house service, inclusive of cleaning, inspection, &c.	20
Power and car-house expenses	6
Track service	8
Repairs to engines, generators, line machinery, electric-power equipment, and miscellaneous . . .	13
Repairs to cars, trucks, and motors	78
Repairs to track, overhead construction, and buildings	47
Track cleaning, train and shop expenses . . .	14
Injury to persons and property	10
Legal, secret service, and insurance	8
Licences and taxes	7
General and miscellaneous expenses	32
Total	478

CABLE ROAD.—WORKING COST PER DAY.

	Dols.
Five and a-half tons coal at $2·50	13¾
Water, oil, and grease	3¼
Depreciation of rope	35
Sixty-six grip-men and conductors at $2	132
Power and car-house service	28
Track service	8
Repairs to engines and line machinery	2
Repairs to grips and cars	7
Repairs to track and buildings	6
House, track, and cable expenses	6
Injury to persons and property	4
Licences and taxes	7
General and miscellaneous expenses	23
Total	275

The items are carefully stated in the same form where that is possible, and the different class of work renders it impossible in others. The great economy in the matters of coal and repairs with the cable system is readily noticeable. With a maximum speed of 8 miles an hour (the average being about 6) for 19½ hours per day, each train would make 110 miles per day, and 15 trains would make 1,650 train-miles, or 3,300 car-miles. The total operating expenses would therefore be 14·5 cents per car-mile for the electric, and rather over 8·3 cents for the cable. The point is that the cable is fully 3d. per car-mile cheaper to work on a two-minute (car) headway than the electric road. This on the mileage gives a saving of over £41 per day, or £12,911 per year, exclusive of Sundays. At 5 per cent. interest that represents a capital of £258,220. It can thus be readily seen that in the long run the cable is much cheaper than the electric system for heavy work. In estimating the operating expenses of cable tramways, it has to be remembered that about one-half the cost remains unchanged by any alteration in the amount of the traffic, while the other half varies as the traffic varies. With electricity, on the other hand, about one-third of the cost remains constant by a limited increase or decrease in the traffic, while the other two-thirds varies as the traffic varies. Hence, again, let us have electricity for light traffic, and cable for the severe work.

The variations of working cost, for materials and wages for repairs only, are exemplified in the following instances, in which general charges are not included:—

	Pence per mile.
Bessbrook and Newry Tramway:—Wages, maintenance and repair, stores	3·94
City and South London Railway:—Working and repairs, generator station, 4·59, locomotive service, 2·31	6·90
Blackpool Electric Tramway:—Repairs, total wages, excluding general charges, coal, and stores	5·34
Birmingham Central Tramways:—Electric haulage, 5·15, machinery, ·29	5·44

It is to be noted that the rails of the South London and City line are not grooved, and that their resistance is much less than that of grooved rails, as already shown by results of trials. Nevertheless, the cost for the South London line is the highest in the group. But the speed is also the highest.

Further comparative evidence is wanted.

CHAPTER IV.

POINTS AND CROSSINGS.

THE most usual combinations of points and crossings, whereby the rolling stock may be shifted from one line of rails to another, are shown diagrammatically in Plate XII. (Figs. 392 to 408).

Fig. 392 shows a passing-place on a single line; Fig. 393, a "triangle" junction of single lines; Fig. 394, a single cross-over road; and Fig. 395, a double cross-over road.

Points are of three types:—Open, when both points of a pair are open; fixed, when one point is fixed, and the other moveable; moveable, when both points of a pair are moveable.

Open points are known also as dumb or dummy points. A broken section of the open point—box section—is shown in Fig. 396. The upper part is chilled, or hardened. The chill usually penetrates to a depth of from ⅛ inch to ⅝ inch in depth. Open points are employed for running-out or trailing points, or as facing points on horse-worked lines, where alternative routes diverge, the car being pulled over by the horses to the desired line.

Fixed points are required for automatically compelling entering cars to take one and the same direction. It is usual to fill up the right-hand groove of the right-hand point at its entrance, thus forcing the entering car to take the left-hand road.

The moveable chilled tongue points (Figs. 397, 398) are employed principally where the cars are to take alternative routes. A tongue may be automatically held over to one hand by means of a spring. The pair of points are suited for girder rails, with fish-plates fused in the ends, in the proper positions for being bolted up to the rails. But the outside fish-plate of each pair, at one or at each end, may be left loose.

Crossings are made to any required angle. The usual angle for passing-places, sidings, and cross-over roads is 1 in 5 or 1 in 6. Sharper angles, up to 1 in 9, are sometimes taken; and larger angles down to 1 in 2½. Ordinary crossings are shown in Figs. 399 and 400. They are suitable for cross-over roads, passing places, branches, and sidings. The first of these shows end chairs to receive the channel rail. In the second, fish-plates are fused in the ends, to connect to the girder rail. The outside fish-plate of each pair at one or both ends may be loose.

Chilled cast iron, as just described, is generally used as the material of points and crossings. It is the hardest of materials.

Cast steel annealed is extensively used on steam tramways. Though less hard than chilled cast iron, it is tougher.

In built up points, made from the rolled Bessemer steel rail, the steel is generally uniform in temper, and harder than annealed cast steel. Mr. James More* considers rail steel to be more durable than annealed cast steel, or chilled cast iron. An example of built-up points, made from 7-inch girder rails, is shown in Figs. 401, 402, 403. Cross-sections of these points are shown in Figs. 404, 405.

A moveable point, made from the rail, is shown in plan and elevation in Figs. 406, 407.

A built-up crossing is shown in Fig. 408, made from the rails used on the line. The running-through rail should be from 10 to 12 feet long, and the crossing rail from 8 to 10 feet long, in order to break joint.

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* See a paper on "Tramway Permanent Way," by James More, Jun., in the *Minutes of Proceedings of the Institution of Civil Engineers*, vol. ciii., 1890-91.

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Crossings are made to any required angle.
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APPENDIX A.

PARLIAMENTARY AND OFFICIAL REGULATIONS.

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PARLIAMENTARY AND OFFICIAL REGULATIONS.

I.—THE TRAMWAYS ACT, 1870.

THIS statute, 33 & 34 Vict. c. 78, the full title of which is "An Act to facilitate the construction and to regulate the working of Tramways"—is the principal enactment dealing with tramways in Great Britain. The Act does not extend to Ireland (s. 2). Previous to the passing of the Act, the decisions of the Examiner and of the Standing Committee of the House of Lords on the Liverpool Tramway Bill of 1866 had rendered it necessary for promoters of tramways to deposit plans and sections of their proposed undertakings.

Provisional Orders.

PART I. of the Act deals with PROVISIONAL ORDERS authorising the construction of tramways, and provides (s. 4) that the Local Authority (see *post*, p. 673) of any district may obtain such Orders for tramways in their district; and the like power is given to any other person or persons, corporation or company, with the consent of the Board of Trade and the Local Authority, but not otherwise. Any such Local Authority, person, persons, corporation, or company obtaining such Provisional Order, are to be deemed promoters of the tramway (s. 4).*

Upon application for a Provisional Order being made to the Board of Trade, the Board are to consider the application, and may, if they think fit, direct inquiries as to the propriety of proceeding upon such application, and they are to consider any objection thereto that may be lodged with them, and to determine whether or not the promoters may proceed with the application (s. 7).

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* TRAMWAYS ORDERS CONFIRMATION ACTS.—Provisional Orders made by the Board of Trade under the authority of the Tramways Act, 1870, to acquire final validity and force, must be confirmed by special Acts of Parliament. These are distinguished as "Tramways Orders Confirmation Acts," by which the Orders set out in the Schedules to the Acts respectively are confirmed.

[At pp. 673—693, *post*, will be found the full text of the Rules issued by the Board of Trade with respect to Provisional Orders.]

Where it appears to the Board of Trade expedient, they may make a Provisional Order, which Order shall empower the promoters to make the tramway upon the gauge and in the manner therein described, and shall contain such provisions as (subject to the requirements of the Act) the Board of Trade, according to the nature of the application and the facts and circumstances of each case, shall think fit; but such Order is not to contain any provision for acquiring lands, except to an extent therein limited, and only then by agreement, or to construct a tramway elsewhere than along or across a road, or upon land taken by agreement (s. 8).

Tramways shall be constructed as near as may be in the middle of the road, and shall not be so laid that, for a distance of 30 feet or upwards, a less surface than 9 feet 6 inches shall intervene between the outside of the footpaths on either side of the road, and the nearest rail of the tramway, if one-third of the owners or one-third of the occupiers of the houses, shops, or warehouses abutting upon the part of the road where such less space shall intervene, as aforesaid, express their dissent from any tramway being so laid (s. 9).

The nature of the traffic on the tramway, and the tolls to be taken, are to be specified in the Provisional Order (s. 10).

The Provisional Order is not to be granted until the promoters deposit in a bank as there prescribed, a sum of not less than 4 per cent. upon the estimated expense, or security of equal value is deposited (s. 12).

The Provisional Order is not to have any operation, until confirmed, with or without amendment, by an Act of Parliament, and it is to be open to parties to petition against the Act and to appear and oppose the Bill in Committee (s. 14).

The Board of Trade, on the application of the promoters, may revoke, amend, extend, or vary such Provisional Order by a further Provisional Order, but the application for every such Provisional Order will be subject to the same conditions as the former Provisional Order, and will require confirmation by an Act of Parliament (s. 16).

If the promoters do not complete the tramway and open it for public traffic within two years of the date of the Order, or within any shorter period prescribed in the Order; or if, within one year from either of those times, the works are not substantially commenced, or, if commenced, are suspended without a reason sufficient in the opinion of the Board of Trade, the powers given by the Order shall cease, except as to so much of the same as is then completed, unless the time be prolonged by the Board, and as to so much of the same as is then completed, the Board may allow the powers to continue and to be exercised if they think fit; but, failing such permission, then so much of the tramway as is then completed shall be deemed to be discontinued, and dealt with accordingly (s. 18).

When a tramway has been made by a Local Authority, or possession has been acquired by a Local Authority, they may, with the consent of the Board of Trade, lease to any person the right of user thereof, and of demanding and taking authorised tolls and charges; or the Local Authority may leave such tramways open to be used by the public, and may, in respect of such cases, take the tolls and charges authorised; but no Local Authority can place or run carriages upon such tramways, and demand and take tolls and charges in respect of the use of such carriages. Every such lease shall be for a term not exceeding twenty-one years, and at its expiration such lease may, with the consent of the Board, be renewed for a further term not exceeding in any case twenty-one years; the lease to be void if the lessees discontinue the working of the tramway (s. 19).

Special provision is made by the Act for payment out of the local rate of all expenses incurred by a Local Authority in obtaining and carrying into effect a Provisional Order authorising the construction of tramways (ss. 20, 21).

Construction of Tramways.

PART II. of the Act relates to the CONSTRUCTION OF TRAMWAYS, and (together with Part III.) is to be incorporated with every Provisional Order or special Act authorising a tramway, except so far as they may be expressly varied thereby (ss. 22, 23, 24).

If no gauge is prescribed by the special Act, the gauge is to be such as to admit of the use on the tramways of carriages constructed for use upon railways of a gauge of 4 feet 8½ inches. They are to be laid on a level with the surface of the road (s. 25).

Powers are given to promoters to break up streets; and provision is made for the completion of the works and the reinstatement of the road, for the repair of the part of the road where the tramway is laid, and for contracts between the road authority and the promoters for paving roads on which tramways are laid; also for the case of interference with the mains of gas and water companies, and for the protection of sewers, drains, and the like (ss. 26—31).

The Act further preserves the rights of authorities and companies, &c., to open roads (s. 32), and provides for the settlement of all differences that may arise between the promoters and the road authority or other body or person by a referee to be appointed by the Board of Trade (s. 33).

General Provisions.

PART III. of the Act contains GENERAL PROVISIONS relating to the working of tramways.

Carriages.—The promoters are to have the exclusive use of the tramways for carriages with flange-wheels or other wheels suitable only to run on the prescribed rail, to be moved by the power prescribed by the Special Act; and, where no such power is prescribed, by animal power only. No carriage shall extend beyond the outer edge of the wheels of such carriage more than 11 inches on each side (s. 34).

Licenses.—If the Local Authority or twenty inhabitant ratepayers, satisfy the Board of Trade that the public are deprived of the full benefit of the tramway, licenses to use it may be granted to third parties by the Board of Trade on certain prescribed conditions, provision being made by the Act for enforcing payment of tolls, &c. (ss. 35—41).

Discontinuance of Tramways.—If the working of a tramway, or of any part thereof, is discontinued for the space of three months (such discontinuance not being occasioned by circumstances beyond the control of the promoters), the powers of the promoters in respect of such disused tramway, or portion thereof, may be determined by an order of the Board of Trade. At any time after two months from the date of such order, the road authority may remove the disused portion of tramways at the cost of the promoters (s. 41).

Insolvency of Promoters.—If at any time after opening of a tramway for traffic the promoters appear to be insolvent or unable to maintain the tramway, the Board of Trade, on the application of the Local Authority or road authority, and after enquiry by a referee, may make an order declaring that the powers of the promoters shall cease at the expiration of six months from the date of the order, unless the same are purchased by the Local Authority, who may, in that event, remove the tramway at the cost of the promoters (s. 42).

Purchase and Sale of Tramways.—Where the promoters of a tramway are not the Local Authority, the Local Authority may, within six months after the expiration of a period of twenty-one years from the time when such promoters were empowered to construct such tramway, and within six months after the expiration of every subsequent period of seven years, or within three months after any order made by the Board of Trade under ss. 41, 42, with the approval of the Board of Trade, require the promoters to sell their undertaking, upon terms of paying the then value (exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory sale, or other consideration whatsoever) of the tramway, and all lands, buildings, works, materials, and plant of the promoters suitable to and used by them for the purposes thereof, such value to be in case of difference determined by a referee nominated by the Board of Trade.

The Local Authority in any district may pay the purchase money and all expenses incurred by them in so purchasing an undertaking out of the like rate, and shall have the like powers of borrowing on the security of the rate, as if such expenses were incurred in obtaining and carrying into effect a Provisional Order under the Act.

Two or more Local Authorities may jointly purchase any undertaking within their several districts (s. 43).

Where a tramway has been opened for traffic for six months the promoters may, with the consent of the Board of Trade, sell their undertaking to any person, persons, corporation, or company, or to the Local Authority of the district; and where such sale is made to the Local Authority such Local Authority may pay the purchase money in like manner as if such purchase were made under the authority of the 43rd section (s. 44).

Tolls.—The promoters or lessees of a tramway authorised by special Act may demand and take tolls and charges as specified in the special Act, such tolls and charges to be exhibited in a conspicuous place inside and outside each tramway carriage (s. 45).

Byelaws.—The Local Authority are empowered to make byelaws as to the rate of speed, the clear distances between any two carriages travelling on the same line of rails, the stopping of carriages using the tramway, and the traffic on the road in which the tramway is laid; and the promoters or lessees of a tramway may also make byelaws for the prevention of any nuisance in or about their carriages or premises and the regulation of travelling upon the carriages. The byelaws are to be subject to allowance by the Board of Trade, and may prescribe penalties (ss. 46, 47).

[For Forms of Byelaws issued by the Board of Trade, see *post*, p. 694]

Power is given to the Local Authority to license the drivers and conductors of tramways (s. 48).

Offences.—Penalties are imposed for obstruction of promoters in laying-out a tramway; for wilful injury or obstruction to tramways or works; for frauds practised or attempted by passengers; for bringing dangerous goods on a tramway, &c. (ss. 49—53).

Any person, not duly authorised, using a tramway with carriages having flange-wheels, or other wheels suitable only to run on such tramway, becomes liable to a penalty not exceeding £20 (s. 54).

Accidents and Injuries.—The promoters or lessees are to be answerable for all accident, damages, and injuries happening through their act or default, or through the act or default of any person in their employment by reason or in consequence of any of their works or carriages (s. 55).

Recovery of Tolls and Penalties. — All tolls, penalties, and charges under the Act, or under a byelaw, may be recovered and enforced in England before two justices of the peace under the Summary Conviction Act, and in Scotland before the sheriff or two justices as penalties under the Railway Clauses Consolidation (Scotland) Act, 1845 (s. 56).

Right of User of Road only.—The promoters of a tramway shall not be deemed to acquire any right other than that of user of any road along or across which they lay the tramway, and nothing contained in the Act is to exempt the promoters, or other person using a tramway, from the payment of tolls to the trustees of a turnpike road. With the approval of the Board of Trade, the trustees of a turnpike road and the promoters of a tramway may enter into agreements for the payment of a composition in respect of the user of such road (ss. 57, 58).

Mines and Minerals under Tramways.—Nothing in the Act is to limit or interfere with the rights of any owner or occupier of mines or minerals lying under or adjacent to a road along or across which a tramway is laid; nor shall any such owner or occupier be liable to make compensation for damage occasioned to such tramway by the working of the mines in ordinary course (s. 59).

Public Rights.—Nothing in the Act is to restrict the powers by law of existing authorities to widen, alter, divert, or improve any road, railway, tramway, or inland navigation; or to limit the powers of the police or Local Authorities to regulate the traffic of the road; or to abridge the right of the public to pass along or across any part of a road along or across which a tramway is laid with carriages not having flange-wheels (ss. 60, 61, 62).

Public Inquiries.—Inquiries which by the Act the Board of Trade are empowered to make are to be made according to the provisions set forth in the Act (s. 63).

Board of Trade Rules.—Power is given to the Board of Trade from time to time to make and amend Rules for carrying the Act into effect; and any Rules so made are to be laid before Parliament (s. 64).

II.—BOARD OF TRADE RULES WITH RESPECT TO PROVISIONAL ORDERS AND OTHER MATTERS UNDER THE TRAMWAYS ACT, 1870.*

BY WHOM PROVISIONAL ORDERS MAY BE OBTAINED AND THE NECESSARY CONSENTS THERETO.

By the Tramways Act, 1870, it is provided as follows:—

" PART I.—*Provisional Orders authorizing the Construction of Tramways.*

SECTION 4.—"Provisional Orders authorizing the construction of tramways in any district may be obtained by—

"(1.) The local authority of such district; or by—
"(2.) Any person, persons, corporation, or company, with the consent of " the local authority of such district; or of the road authority of such " district where such district is or forms part of a highway district " formed under the provisions of 'The Highway Acts.'

* * * * * *

" Application for a Provisional Order shall not be made by any local " authority until such application shall be approved in the manner prescribed " in Part III. of the Schedule A. to this Act annexed. (This schedule follows " on page 3.)

" Where in any district there is a road authority distinct from the local " authority, the consent of such road authority shall also be necessary in any " case where power is sought to break up any road subject to the jurisdiction " of such road authority, before any Provisional Order can be obtained."

Definition of Terms.—Section 3 provides that for the purposes of the Act—

The terms " local authority " and " local rate " shall mean respectively the bodies of persons and rate named in the table in Part I. of the Schedule (A. to this Act annexed.

The term " road " shall mean any carriageway being a public highway, and the carriageway of any bridge forming part of or leading to the same.

The term "road authority " shall mean, in the districts specified in the table in Part II. of the Schedule (A.) to this Act annexed, the bodies of persons named in the same table, and elsewhere any local authority, board, town council, body corporate, commissioners, trustees, vestry, or other body or persons in whom a road as defined by this Act is vested, or who have the power to maintain or repair such road.

The term "district" in relation to a local authority or road authority shall mean the area within the jurisdiction of such local authority or road authority.

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* NOTES.—(1) All memorials, objections, and other documents addressed to the Board of Trade under the Act should be on paper of foolscap size. (2) Promoters who desire to be incorporated must register themselves under the Companies Act, 1862.

"SCHEDULE A.—(PART I.)

"LOCAL AUTHORITY.

Districts of Local Authorities.	Description of Local Authority of District set opposite its Name.	The Local Rate.
	ENGLAND & WALES.	
"The city of London "and the liberties "thereof.	The mayor, aldermen, and commons of the city of London.	The consolidated sewers rate.
"The metropolis (*a*) .	The Metropolitan Board of Works (*c*).	The metropolitan consolidated rate.
"Boroughs (*b*) . .	The mayor, aldermen, and burgesses acting by the council.	The borough fund or other property applicable to the purposes of a borough rate, or the borough rate.
"Any place not included "in the above de-"scriptions, and under "the jurisdiction of "commissioners, trus-"tees, or other persons "intrusted by any "Local Act with "powers of improving, "cleansing, or paving "any town.	The commissioners, trustees, or other persons intrusted by the Local Act with powers of improving, cleansing, or paving the town.	Any rate leviable by such commissioners, trustees, or other persons, or other funds applicable by them to the purposes of improving, cleansing, or paving the town.
"Any place not included "in the above descrip-"tions, and within "the jurisdiction of a "local board consti-"tuted in pursuance "of the Public Health "Act, 1848, and the "Local Government "Act, 1858, or one of "such Acts.	The local board . .	General district rate.
"Any place or parish "not within the above "descriptions, and in "which a rate is levied "for the maintenance "of the poor.	The vestry, select vestry, or other body of persons acting by virtue of any Act of Parliament, prescription, custom, or otherwise, as or instead of a vestry or select vestry.	The poor rate.

	“ Scotland.	
“ Places within the jurisdiction of any town council, and not subject to the separate jurisdiction of police commissioners or trustees.	The town council.	The prison assessment or police assessment, as the local authority shall resolve.
“ In places within the jurisdiction of police commissioners or trustees exercising the functions of police commissioners under any General or Local Act.	The police commissioners or trustees.	
“ In any parish or part thereof over which the jurisdiction of a town council or of police commissioners or trustees exercising the functions of police commissioners does not extend.”	The road trustees having the management of any road on which a tramway is proposed to be constructed.	The tolls, duties, and assessments leviable by the road trustees.

“ Schedule A.—(Part II.)

“ Road Authority.

Districts of Road Authorities.	Description of Road Authority of Districts set opposite its Name.
“ Parishes within the Metropolis (1) mentioned in Schedule (A.) to the Metropolis Management Act, 1855.	The vestries appointed for the purposes of the Metropolis Management Act, 1855.
“ Districts within the Metropolis (1) formed by the union of the parishes mentioned in schedule (B.) to the Metropolis Management Act, 1855.”	The board of works for the district appointed for the purpose of the Metropolis Management Act, 1855.

“ (*a*) ‘The metropolis’ shall include all parishes and places in which the Metropolitan Board of Works have power to levy a main drainage rate, except the city of London and the liberties thereof.”

“ (*b*) ‘Borough’ shall mean any place for the time being subject to an Act passed in the session holden in the fifth and sixth years of the reign of King William the Fourth, chapter seventy-six, intituled ‘An Act to provide for the regulation of municipal corporations in England and Wales.’ ”

(*c*) Now London County Council.

"SCHEDULE A.—(PART III.)

"*Evidence of Approval and Consent.*—The approval of any intended "application for a Provisional Order by a Local Authority shall be in manner "following; that is to say,

"A resolution approving of the intention to make such application shall "be passed at a special meeting of the members constituting such Local "Authority.

"Such special meeting shall not be held unless a month's previous notice "of the same, and of the purpose thereof, has been given in the manner in "which notices of meetings of such Local Authority are usually given.

"Such resolution shall not be passed unless two-thirds of the members "constituting such Local Authority are present and vote at such special "meeting, and a majority of those present and voting concur in the "resolution; provided that if in Scotland the local authority be the road "trustees, it shall not be necessary that two-thirds of such trustees shall "be present at the meeting, but the resolution shall not be valid unless "two-thirds of the members present vote in favour of such resolution, and "unless the said resolution is confirmed in like manner at another "meeting called as aforesaid, and held not less than three weeks and not "more than six weeks thereafter. Where any such resolution relating to "the metropolis as the same is defined in Part I. of the Schedule, or to "any district in Scotland of which road trustees are the local authority, "has been passed in manner aforesaid, the intended application to "which such resolution relates shall be deemed to be approved."

RULES OF THE BOARD OF TRADE.

RULE I.—*Approval of Application made by Local Authorities.*—Where the application is made by any Local Authority, the evidence of approval required as above by Schedule A. (PART III.) of the Act must be given at the time fixed for proving compliance with the Act and these Rules, by (*a*) a certified copy of the resolution approving of the intention to make the application, (*b*) a certified copy of the notice convening the special meeting to consider the application, and (*c*) a certified statement of the number of members constituting the Local Authority, and of the number present and voting at such special meeting.

RULE II.—*Consent to Applications not made by Local Authorities.*—Where an application is made by promoters, not being the Local Authority of the district in which the tramway is proposed to be laid, evidence of the consent required by PART I., section 4 of the Act, must be given at the time fixed for proving compliance with the Act and these Rules, by (*a*) a certified copy of the resolution passed at a meeting of the local or road authority, as the case may be, at which the application was approved, (*b*) a copy of the notice convening the meeting, which notice must contain a statement that the subject of the proposed tramway will be brought before the meeting.

Similar evidence of the consent of the local and road authorities must be produced in cases in which the promoters seek to use steam or other mechanical power on any tramway or tramways already authorised.

ADVERTISEMENT AND NOTICES IN OCTOBER OR NOVEMBER AND DECEMBER.

SECTION 6.—"The promoters intending to make an application for a "Provisional Order shall proceed as follows :—

"(1.) In the months of October and November next before the application, "or in one of those months, they shall publish notice of their intention "to make such application by advertisement; and they shall, on or "before the fifteenth day of the following month of December, serve "notice of such intention in accordance with the Standing Orders (if "any) of both Houses of Parliament for the time being in force with "respect to Bills for the construction of tramways. (See Schedule "B., Part I.)

"(2.) On or before the thirtieth day of the same month of November they "shall deposit the documents described in part two of the same* "schedule, according to the regulations therein contained :

"(3.) On or before the twenty-third day of December in the same year "they shall deposit the documents described in part three of the "same† schedule, according to the regulations therein contained."

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"SCHEDULE B.—(PART I.)

"(1.) Every advertisement is to contain the following particulars :—

"1. The objects of the intended application.
"2. A general description of the nature of the proposed works, if any.
"3. The names of the townlands, parishes, townships, and extra-parochial "places in which the proposed works, if any, will be made.
"4. The times and places at which the deposit under Part II. of this "schedule will be made.
"5. An office, either in London or at the place to which the intended "application relates, at which printed copies of the Draft Provisional "Order, when deposited, and of the Provisional Order, when made, "will be obtainable as hereinafter provided.

"(2.) The whole notice is to be included in one advertisement, which is to "be headed with a short title descriptive of the undertaking.

"(3.) The advertisement is to be inserted once at least in each of two successive weeks in some one and the same newspaper published in the "district affected by the proposed undertaking, where the proposed works, if

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* Schedule B. (on page 5).
† Schedule B. (on page 6).

"any, will be made; or if there be no such newspaper, then in some one and
"the same newspaper published in the county in which every such district, or
"some part thereof, is situate; or if there be none, then in some one and the
"same newspaper published in some adjoining or neighbouring county."

"(4.) The advertisement is also, in every case, to be inserted once at least
"in the London or Edinburgh *Gazette*, accordingly as the district is situate in
"England or Scotland."

RULE III.—*Description of Tramways in Advertisement.*—The tramways mentioned in the advertisement of the intended application should be described in the manner prescribed in Rule XVI., but the length need not be inserted.

RULE IV.—*Advertisement as to Narrow Places.*—The advertisement must specify at what point or points, and on which side of the street or road, it is proposed to lay such tramway, so that for a distance of thirty feet or upwards a less space than nine feet six inches, or if it is intended to run thereon carriages or trucks adapted for use upon railways, a less space than ten feet six inches, shall intervene between the outside of the footpath on the side of the street or road and the nearest rail of the tramway. The notice shall also specify the gauge to be adopted, and what power it is intended to employ for moving carriages or trucks upon the tramway.

RULE V.—*Street Notice.*—In the months of October and November, or one of them, immediately preceding the application for any Provisional Order, a notice thereof shall be posted for fourteen consecutive days in every street or road, along which it is proposed to lay the tramway, in such manner as the authority having the control of such street or road shall direct: and if after application to such authority no such direction shall be given, then in some conspicuous position in such street or road; and such notice shall also state the place or places at which the plans of such tramway will be deposited.

RULE VI.—*Notice to Owners and Lessees of Railways, Tramways, and Canals.*—On or before the 15th day of December immediately preceding the application for any Provisional Order for laying down a tramway crossing any railway or tramway on the level, or crossing any railway, tramway, or canal by means of a bridge, or otherwise affecting or interfering with such railway, tramway, or canal, notice in writing of such application shall be served upon the owner or reputed owner and upon the lessee or reputed lessee of such railway, tramway, or canal, and such notice shall state the place or places at which the plans of the tramway to be authorised by such Provisional Order have been or will be deposited.

Similar notice must also be given to County Councils and to proprietors of navigable rivers in respect of their bridges or other works which are proposed to be crossed or otherwise interfered with.

Every notice under this rule must be accompanied by a copy of Rule XVII., omitting the first paragraph, and must state where copies of the draft Provisional Order, when deposited at the Board of Trade, can be obtained.

RULE VII.—*Notice to Local and Road Authorities.*—Where the promoters make application for an extension of time for the construction of, or for authority to abandon, any tramway, they must, on or before the 15th day of December, serve notice of such application upon all the local and road authorities affected.

RULE VIII.—*Intimation to intending Objectors.*—The preceding advertisement and notices, other than the street notice, must state that every company, corporation, or person desirous of making any representation to the Board of Trade, or of bringing before them any objection respecting the application, may do so by letter, addressed to the Assistant Secretary of the Railway Department of the Board of Trade, *on or before the 15th January* next ensuing; that copies of their objections must at the same time be sent to the promoters; and that in forwarding to the Board of Trade such objections, the objectors or their agents should state that a copy of the same has been sent to the promoters or their agents.

RULE IX.—*Notice to Frontagers.*—On or before the 15th day of December immediately preceding the application for a Provisional Order, notice in writing must be given to the owners or reputed owners, lessees or reputed lessees, and occupiers of all houses, shops, or warehouses abutting upon any part of any street or road where, for a distance of thirty feet or upwards, it is proposed that a less space than nine feet six inches shall intervene between the outside of the footpath on either side of the road and the nearest rail of the tramway.

This notice shall be given in respect of such premises on both sides of the road, and must contain a notification that if such owner, lessee, or occupier dissents from the tramway being so laid, he may express his dissent by a statement in writing, addressed to the Assistant Secretary of the Railway Department of the Board of Trade, *on or before the 1st January* next ensuing, and that he must at the same time send a copy of his dissent to the promoters.

DEPOSITS ON OR BEFORE 30TH NOVEMBER.

" SCHEDULE B.—(PART II.)

" (1.) The promoters are to deposit—

" 1. A copy of the advertisement published by them.

" 2. A proper plan and section of the proposed works, if any, such plan and " section to be prepared according to such regulations as may from time to " time be made by the Board of Trade in that behalf.

" (2.) The documents aforesaid are to be deposited for public inspection—

" In England, in the office of the clerk of the peace for every county, riding, " or division, and of the parish clerk of every parish, and the office " of the local authority of every district in or through which any such " undertaking is proposed to be made; in Scotland, in the office of the " principal sheriff clerk for every county, district, or division which " will be affected by the proposed undertaking, or in which any " proposed new work will be made.

" (3.) The documents aforesaid are also to be deposited at the office of the " Board of Trade."

RULE X.—*Map and Diagram.*—A published map of the district on a scale of not less than six inches to a mile (or, if no map on such a scale be published, then the best map obtainable), with the line of the proposed tramway marked thereon, and a diagram on a scale of not less than two inches to a mile prepared in accordance with the specimen appended to these rules, must also be deposited on or before the 30th of November.

RULE XI.—*Requirements as to Plans.*—The plans to be deposited must also comply with the following requirements:—

The plans shall indicate whether it is proposed to lay the tramway along the centre of any street or road, and if not along the centre, then on which side of, and at what distance from, an imaginary line drawn along the centre of such street or road, and whether or not, and if so, at what point or points, it is proposed to lay such tramway, so that for a distance of thirty feet or upwards a less space than nine feet six inches, or if it is intended to run thereon carriages or trucks adapted for use upon railways, a less space than ten feet six inches, shall intervene between the outside of the footpath on either side of the street or road and the nearest rail of the tramway.

All lengths shall be stated on the plan and section in miles, furlongs, chains, and decimals of a chain.

The distance in miles and furlongs from one of the termini of each tramway shall be marked on the plan and section.

Each double portion of tramway, whether a passing-place or otherwise, shall be indicated by a double line.

The total length of the street or road upon which each tramway is to be laid shall be stated (*i.e.* the length of route of each tramway).

The length of each double and single portion of such tramway, and the total length of such double and single portions respectively, shall also be stated.

In the case of double lines (including passing-places), the distance between the centre lines of each line of tramway shall be marked on the plans. This distance must in all cases be sufficient to leave at least 15 inches between the sides of the widest carriage and engines to be used on the tramways when passing one another.

The gradients of the street or road on which each tramway is to be laid shall be marked on the section.

Every crossing of a railway, tramway, river, or canal shall be shown, specifying in the case of railways and tramways whether they are crossed over, under, or on the level.

All tidal waters shall be coloured blue.

All places where for a distance of 30 feet and upwards there will be a less space than nine feet six inches between the outside of the footpath on either side of the street or road and the nearest rail of the tramway shall be indicated by a thick dotted line on the plans and on the side or sides of the line of tramway where such narrow places occur, as well as noted on the plans, and the width of the street or road at these places shall also be marked on the plans.

Note.—The section of each tramway should, where practicable, be shown on the same page as the plan.

RULE XII.—*Plans in certain cases to be in Duplicate.*—The plans to be deposited with the clerk of the peace or sheriff clerk (as the case may be) must be in duplicate. (*See* Standing Orders of the House of Lords and of the House of Commons.)

RULE XIII.—*Portions only of Plans required in certain cases.*—In cases where the proposed works are intended to be made in or through one or more parishes or districts, the deposit with the parish clerks or Local Authorities need consist only of a copy of so much of the plans and sections as relates to their respective parishes or districts.

RULE XIV.—*Plans, &c., to be Deposited in Parliament.*—The following Standing Orders must also be complied with* :—

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* These Standing Orders refer to *amended* as well as to original plans.

STANDING ORDER OF THE HOUSE OF LORDS.

"Whenever plans, sections, books of reference, or maps are deposited in the case of an application to any public department or county council for a Provisional Order or Certificate, duplicates of the said documents shall at the same time be deposited in the office of the Clerk of the Parliaments, provided that with regard to such deposits as are so made at any public department or with any county council after the prorogation of Parliament and before the thirtieth day of November in any year, such duplicates shall be so deposited on or before the thirtieth day of November."

STANDING ORDER OF THE HOUSE OF COMMONS.

"Whenever plans, sections, books of reference, or maps are deposited in the case of any application to any public department or county council for a Provisional Order or Provisional Certificate, duplicates of the said documents shall at the same time be deposited in the Private Bill Office, provided that with regard to such deposits as are so made at any public department or with any county council after the prorogation of Parliament, and before the thirtieth day of November in any year, such duplicates shall be so deposited on the thirtieth day of November."

DEPOSITS ON OR BEFORE 23RD DECEMBER.

"SCHEDULE B.—(PART III.)

"(1.) The promoters are to deposit at the office of the Board of Trade—

"1. A memorial signed by the promoters, headed with a short title "descriptive of the undertaking (corresponding with that at the head of "the advertisement), addressed to the Board of Trade, and praying "for a Provisional Order.

"2. A printed draft of the Provisional Order as proposed by the promoters, "with any schedule referred to therein.

"3. An estimate of the expense of the proposed works, if any, signed by "the persons making the same.

"(2.) They are also to deposit a sufficient number of such printed copies at "the office named in that behalf in the advertisement; such copies to be "there furnished to all persons applying for them at the price of not more "than one shilling each.

"(3.) The memorial of the promoters (to be written on foolscap paper, "bookwise, with quarter margin) is to be in the following form, with such "variations as circumstances require:

"[*Short title of undertaking.*]

"To the Board of Trade.

"The memorial of the promoters of [*short title of undertaking*]

"Showeth as follows:

"1. Your memorialists have published in accordance with the requirements "of the Tramways Act, 1870, the following advertisement:

"[*Here advertisement to be set out verbatim.**]

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* This advertisement may be in print and fixed to the body of the memorial.

"Your memorialists have also deposited, in accordance with the require-"ments of the said Act, copies of the said advertisement and [*here state* "*deposit of the several matters required by Act*].

"Your memorialists therefore pray that a Provisional Order "may be made in the terms of the draft proposed by your "memorialists, or in such other terms as may seem meet.

"*A.B.*
"*C.D.* } Promoters."

RULE XV.—The following documents, &c., must also be deposited at the Board of Trade on or before the 23rd December, viz.:—

(1.) *List of Railways, Tramways, and Canals, and Copy of the Notice.*—A complete list of every railway, tramway, and canal proposed to be crossed or otherwise affected or interfered with, together with the names and addresses of the owners or reputed owners, and of the lessees or reputed lessees thereof, and a certified copy of the notice served upon them.

(2.) *Lists of Local and Road Authorities and Copy of Notice.*—A complete list of the local and of the road authorities through whose districts the proposed tramway is to pass (including in such list the clerk to the County Council in cases where it is proposed to cross county bridges), and if any such district is or forms part of a highway district, under the provisions of "The Highway Acts," a statement to that effect must accompany the deposit. Also a separate list of the local and road authorities affected by any application relating to the use of steam or other mechanical power on authorised tramways, or to an extension of time or abandonment; together with a copy of any notice served under Rule VII.

(3.) *Copy of Street Notice.*—A certified copy of the notice which is required by Rule V. to be posted in the streets in October or November next before the application.

(4.) *List of Frontagers and Copy of Notice.*—In all cases where for a distance of 30 feet or upwards it is proposed that a less space than nine feet six inches shall intervene between the outside of the footpath on either side of the road and the nearest rail of the tramway, or a less space than ten feet six inches if it is intended to run on the tramway carriages or trucks adapted for use upon railways, a complete list of the owners or reputed owners, lessees or reputed lessees, and occupiers of all houses, shops, or warehouses abutting upon any part of the highway, where such less space is proposed, together with a certified copy of the notice which was served on them on or before the 15th December, as required by Rule IX. (The list should be so prepared as to show distinctly and separately every length of street or road where for a distance of 30 feet or upwards such less space is proposed and in respect of every such length of street or road it should indicate in parallel columns the name of the street, the name or number of the house, shop, or warehouse, and the names of the owner or reputed owner, the lessee or reputed lessee, and of the occupier.)

(5.) *Description of Land.*—A description of the land (if any) which the promoters propose to purchase for the construction of the tramway. (The contracts for the purchase of all the lands required must be produced at the time of proving compliance with the Act and these Rules.)

(6.) *Memorandum of Association, &c.*—A list of every Provisional Order or Act of Parliament (if any) of the promoters; and where the promoters are a company incorporated under the Companies Act, 1862, a printed copy of the Memorandum of Association, Articles of Association, and any registered special resolution of the company, and in the case of a company incorporated in any other manner, a copy of every deed or instrument of settlement or incorporation.

(7.) *Fee.*—A fee of £35, by cheque payable to "An Assistant Secretary of the Board of Trade." (This fee will not necessarily be taken to cover the cost of inquiries or other matters arising out of the application. With respect to costs in such matters, security must be given from time to time by the promoters as the Board of Trade may require.)

DRAFT PROVISIONAL ORDER.

RULE XVI.—The following rules must be observed in regard to the draft Provisional Order:—

(1.) The draft Provisional Order must be deposited in triplicate and be printed on *one side only of the page*, so as to leave the back of the page blank, and any schedule annexed must begin a new page.

(2.) The draft Provisional Order must describe where each tramway is to commence and terminate, and must state the streets and roads along which it is to pass, and the total length of the double and single portions respectively of such tramway in miles, furlongs, chains, and decimals of a chain.

(3.) Each double and single portion of such tramway, with its commencement and termination, must also be described. (This can be done by stating that each line or branch line will be double or single throughout, except at certain specified places where it will be single or double.)

(4.) Every passing-place must be described as a double line in accordance with the Standing Order of the House of Lords, which provides that "*two lines of tramway running side by side shall be described as a double line.*"

(5.) In cases where the promoters are individuals their addresses as well as names should be inserted in the draft Order.

(6.) The names and addresses of the agents for the Provisional Order must be printed on the outside of the draft Order, and there must be a notice at the end of it stating that objections are to be addressed to the Assistant Secretary of the Railway Department of the Board of Trade on or before the 15th January next ensuing, that copies of objections must at the same time be sent to the promoters, and that in forwarding to the Board of Trade such objections, the objectors or their agents should state that a copy of the same has been sent to the promoters or their agents.

PROOFS OF COMPLIANCE WITH THE ACT AND RULES.

RULE XVII.—The agent should be prepared to prove compliance with the provisions of the Act and these Rules by the *15th January, and all such proofs must be completed on or before the 22nd February.* Six days' notice will be given of the day and hour at which the agents are to attend for the purpose at the Board of Trade, and printed forms of proof will accompany the notice. These forms should be filled up by the agents, and brought with the requisite documents to the Department at the time fixed for proving compliance.

If any local or road authority, or any railway, tramway, or canal company, or any other company, body, or person desire to have any clauses or other amendments inserted in the Order, they must deliver the same to the agents for the Order, and also to the Board of Trade, not later than the *8th February.*

On or before the 22nd February the agents must deposit at the Board of Trade a filled-up draft printed Order (in duplicate) containing in manuscript all such clauses or other amendments as have been agreed upon.

If any of the clauses or other amendments which have been delivered to the agents are not settled with the consent of both parties, the agents must, so far as they can, on or before the 22nd February, show what are the amendments, if any, which each party would be willing to accept.

After the 22nd February no further proposals for clauses will be entertained by the Board of Trade.

DEPOSIT AND ADVERTISEMENT OF ORDER AS MADE.

"SECTION 13.—When a Provisional Order has been made as aforesaid and "delivered to the promoters, the promoters shall forthwith publish the same "by deposit and advertisement according to the regulations contained in "Part IV. of the Schedule (B.) to this Act."

"SCHEDULE B.—(PART IV.)

"(1.) The promoters are to deposit printed copies of the Provisional Order, "when settled and made for public inspection in the offices of clerks of the "peace and sheriff clerks, where the documents required to be deposited by "them under Part II. of this schedule were deposited.

"(2.) They are also to deposit a sufficient number of such printed copies at "the office named in that behalf in the advertisement, such copies to be "there furnished to all persons applying for them at the price of not more "than* each.

"(3.) They are also to publish the Provisional Order as an advertisement "once in the local newspaper in which the original advertisement of the "intended application was published, or, in case the same shall no longer be "published, in some other newspaper published in the district."

(*Note.*—Section 14 of the Act requires that the Order as made shall be deposited and advertised *not later* than the 25th April.)

RULE XVIII.—*Deposit of Amended Plan and Section.*—Should any alteration of the plan and section originally deposited for the purposes of the Order be made, with the approval of the Board of Trade, before the Order is granted, a copy of such plan and section (or of so much thereof as may be necessary), showing such alteration, must, before the Order is introduced into a Confirmation Bill, be deposited by the promoters for public inspection :—

In England, in the office of the clerk of the peace for every county, riding, or division, and of the parish clerk of every parish, and the office of the Local Authority of every district, affected by such alteration ; and

In Scotland, in the office of the principal sheriff clerk for every county, district, or division affected by such alteration.

Copies of such documents are at the same time to be deposited at the office of the Board of Trade, in the office of the clerk of the Parliaments and at the Private Bill Office.

RULE XIX.—When a Provisional Order has been made, and before it is introduced into the Confirmation Bill, the promoters will be required to submit to the Board of Trade the following proofs, viz. :—

(1.) The receipt of the clerk of the peace or sheriff clerk, or proof by

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[*] The Board of Trade consider that the price to be here inserted should not be more than one shilling.

affidavit of the deposit of the Order with such officer as required by Part IV. of Schedule B. to the Act.

(2) A copy of the local newspaper containing the advertisement of the Order. This advertisement must have a short heading stating that the Order has been made by the Board of Trade under the Tramways Act, 1870, previous to its being introduced into a Confirmation Bill, and must also state the name of the office where printed copies of the Order can be obtained.

(3.) Proof must also be given that the advertised Order is a correct copy of the Order delivered by the Board of Trade to be advertised, that it was inserted in the newspaper in which the original advertisement of the application for the Order was published, and that a sufficient number of printed copies of the Order were deposited for sale at the office named in the original advertisement, with a statement of the price for which they may be obtained.

(4.) Receipts or proof by affidavit of the deposit of amended plans as required by Rule XVIII.

Printed forms for these proofs will be furnished by the Board of Trade when the Order is sent to the promoters to be advertised, and one of these forms must be filled up by the promoters, and brought or forwarded to the Department with the requisite documents *as soon as possible* after the advertisement and deposit have been made.

DEPOSIT OF MONEY, PENALTY FOR NON-COMPLETION OF TRAMWAYS, AND RELEASE OF DEPOSIT.

RULE XX.—*Deposit of Money in the Chancery Division under Section* 12 *of Act.*—After the Provisional Order is ready, and before the same is introduced by the Board of Trade into a Confirming Bill, the *promoters* (unless they are a Local Authority) shall, if they are not possessed of a tramway already opened for public traffic, which has during the year last past paid dividends on their ordinary share capital, pay as a deposit a sum of money not less than five per centum on the amount of the estimate of the expense of the construction of the tramway, as follows; namely,

Where the tramway or any part thereof will be situate in England—to the account of the Paymaster-General for and on behalf of the Supreme Court of Judicature in England to the credit of the particular tramway:

Where the tramway will be situate wholly in Scotland—either to the account of the Paymaster-General for and on behalf of the Supreme Court of Judicature in England in manner aforesaid, or (at the option of the promoters) into a bank in Scotland established by Act of Parliament or Royal Charter, in the name and with the privity of the Queen's Remembrancer of the Court of Exchequer in Scotland *ex parte* the particular tramway.

The Board of Trade may issue their warrant to the promoters for such payment into court, which warrant shall be a sufficient authority for the *persons* therein named, not exceeding five in number, or the majority or survivors of them, to pay the money therein mentioned to the account of the Paymaster-General for and on behalf of the Supreme Court of Judicature in England or into the bank therein mentioned, in the name and with the privity of the officer therein mentioned, if any, and for that officer to issue directions to such bank to receive the same, to be placed to his account there according to the method (prescribed by statute, or general rules or orders of court or otherwise) for the time being in force respecting the payment of money into the said courts respectively, and without fee or reward.

Provided, that in lieu, wholly or in part, of the payment of money, the promoters may bring into court as a deposit an equivalent sum of bank annuities, or of any stocks, funds, or securities on which cash under the control of the respective courts is for the time being permitted to be invested, or of exchequer bills (the value thereof being taken at the price at which the promoters originally purchased the same, as appearing by the broker's certificate of that purchase); and in that case the Board of Trade shall vary their warrant accordingly by directing the transfer or deposit of such amount of stocks, funds, securities, or exchequer bills by the persons therein named.

Where money is so paid into the Supreme Court of Judicature, the court may, on the application of the persons named in the warrant of the Board of Trade, or of the majority or survivors of them, order that the same be invested in such stocks, funds, or securities as the applicants desire and the court thinks fit.

In the subsequent provisions of these Rules, the term "the deposit fund" means the money deposited, or the stocks, funds, or securities in which the same is invested, or the bank annuities, stocks, funds, securities, or exchequer bills transferred or deposited, as the case may be; and the term "the depositors" means the persons named in the warrant of the Board of Trade authorizing the deposit, or the majority or survivors of those persons, their executors, administrators, or assigns.

RULE XXI.—*Penalty for Non-completion of Tramways.*—If the promoters empowered by the Order to make the tramway are possessed of a tramway already opened for public traffic, and which has during the year last past paid dividends on their ordinary share capital, no deposit will be required: but if such promoters (unless they are a Local Authority) do not, within the time in the Order prescribed, or within the time as prolonged by the special direction of the Board of Trade under section 18 of the Tramways Act, 1870, and if none is prescribed, or if the time has not been prolonged as aforesaid, then within two years from the passing of the Act confirming the Order, complete the tramway authorized by the Order, they will be liable to a penalty of £50 a day for every day after the expiration of the period so limited, until the said tramway is completed and opened for public traffic, or until the sum received in respect of such penalty shall amount to five per cent. on the estimated cost of the works; and the said penalty may be applied for by any road authority claiming to be compensated in accordance with the provisions of Rule XXII., and in the same manner as the penalty provided in the third section of the Act 17 & 18 Vict. c. 31, known as "The Railway and Canal Traffic Act, 1854," and every sum of money recovered by way of such penalty as aforesaid shall be paid under the warrant or order of such court or judge as is specified in the said third section of the Act 17 & 18 Vict. c. 31, to an account opened or to be opened in the name and with the privity of the Paymaster-General for and on behalf of the Supreme Court of Judicature in England [the Queen's Remembrancer of the Court of Exchequer in Scotland (according as the tramway is situate in England or Scotland)], in the bank named in such Order, and shall not be paid thereout, except as provided by Rule XXII., but no penalty will accrue in respect of any time during which it shall appear, by a certificate to be obtained from the Board of Trade, that the promoters were prevented from completing or opening such tramway by unforeseen accident or circumstances beyond their control: Provided that the want of sufficient funds will not be held to be a circumstance beyond their control.

RULE XXII.—*Application of Deposit.*—If the promoters empowered by the Order to make the tramway do not within the time in the Order prescribed, or within the time as prolonged by the special direction of the Board of Trade under section 18 of the Tramways Act, 1870, and if none is prescribed, or if the time has not been prolonged as aforesaid, then within two years from the passing of the Act confirming the Order, complete the tramway, and open it for public traffic, then and in every such case the deposit fund, or so much thereof as shall not have been repaid to the depositors (or any sum of money recovered by way of such penalty as aforesaid), shall be applicable, and after due notice in the *London* or *Edinburgh Gazette*, as the case may require, shall be applied towards compensating all road authorities for the expense incurred by them in taking up any tramway or materials connected therewith placed by the promoters in or on any road vested in or maintainable by such road authorities respectively, and in making good all damage caused to such roads by the construction or abandonment of such tramway, and for which expense or damage no compensation or inadequate compensation shall have been paid, and shall be distributed in satisfaction of such compensation in such manner and in such proportions as to the Supreme Court of Judicature in England, or Court of Exchequer in Scotland, as the case may be, may seem fit; and if no such compensation shall be payable, or if a portion of the said deposit fund (or of the sum or sums of money recovered by way of penalty aforesaid) shall have been found sufficient to satisfy all just claims in respect of such compensation, then the said deposit fund (or the sum or sums of money recovered by way of penalty aforesaid), or such portion of it as may not be required as aforesaid, shall in the discretion of the court if the promoters are a company and a receiver has been appointed, or if such company is insolvent and has been ordered to be wound up, be paid or transferred to such receiver, or to the liquidator or liquidators of the company, or be applied in the discretion of the court as part of the assets of the company, for the benefit of the creditors thereof. Subject to such application as aforesaid, the deposit fund may be repaid or re-transferred to the depositors or as they shall direct.

RULE XXIII.—*Release of Deposit.*—The court in which the deposit is made shall, on the application of the depositors, order the deposit fund to be paid or transferred to the applicants, or as they shall direct, if, within the time by the Order prescribed, or within the time prolonged by the special direction of the Board of Trade under section 18 of the Tramways Act, 1870, and if none is prescribed, or if the time has not been prolonged as aforesaid, then within two years from the passing of the Act confirming the Order, the promoters thereby empowered to make the tramway, complete it, and open it for public traffic after inspection by an inspector appointed by the Board of Trade, and upon a certificate of the Board of Trade that the tramway is fit for public traffic, as provided by Rule XXV.: Provided, that if within such time as aforesaid any portion of a line of tramway authorized by an Order is opened for public traffic, after such inspection as aforesaid, and on such certificate under Rule XXV. as aforesaid, then on the production of a certificate of the Board of Trade, specifying the length of the portion of the tramway opened as aforesaid, and the portion of the deposit fund which bears to the whole of the deposit fund the same proportion as the length of the tramway so opened bears to the entire length of the tramway authorized by the Order, the court in which the deposit is made shall, on the application of the depositors, order the said portion of the deposit fund so specified in such certificate as aforesaid to be paid or transferred to them, or as they shall direct.

RULE XXIV.—*Miscellaneous as to Deposits.*—The depositors shall be entitled to receive payment of any interest or dividends from time to time accruing on the deposit fund while in court; and the court in which the deposit is made may from time to time, on the application of the depositors, make such order as seems fit respecting the payment of the interest or dividends accordingly.

If either House of Parliament refuse to confirm any Provisional Order in respect whereof a deposit has been made under these rules, or authorize a portion only of any tramway comprized in such Order, or if any such Provisional Order be withdrawn before the same is confirmed by Parliament, the court shall, upon production of a certificate of the Board of Trade, order the deposit fund or a proportionate part thereof, as the case may be, to be paid to the depositors, or as they shall direct.

The issuing in any case of any warrant or certificate relating to deposit or to the deposit fund, or any error in any such warrant or certificate or in relation thereto, shall not make the Board of Trade, or the person signing the warrant or certificate on their behalf, in any manner liable for or in respect of the deposit fund, or the interest of or dividends on the same, or any part thereof respectively.

Any application under these Rules to the Supreme Court of Judicature shall be made in a summary manner by summons at Chambers.

OPENING OF TRAMWAYS.

RULE XXV.—The promoters shall give to the Board of Trade at least 14 days' notice in writing of their intention to open any tramway, or portion of a tramway, and such tramway or portion of tramway, shall not be opened for public traffic until an Inspector appointed by the Board of Trade has inspected the same, and the Board of Trade has certified that it is fit for such traffic. The above-mentioned notice should be accompanied by the following documents, viz.:

(1.) A copy of the Act or Provisional Order authorizing the construction of the tramways.

(2.) A copy or tracing of so much of the deposited plans and sections as relates to the portion of tramway proposed to be opened, distinguishing between double and single line, and showing in red ink any variations therefrom in the tramways as constructed.

(3.) A list of the local and road authorities concerned.

(4.) A diagram of the lines submitted for inspection, on a scale of about two inches to a mile.

PROLONGATION OF TIME FOR THE COMMENCEMENT OR COMPLETION OF WORKS.

The Board of Trade, under the powers conferred upon them by section 18 of the Tramways Act, 1870, have made the following Rules with respect to applications for a prolongation of time for the commencement or the completion of the works authorized by any Order made under the above-named Act:—

1. The application should be in the form of a memorial setting forth the grounds on which the application is made, and must be made *at least one month before* the expiration of the time prescribed for the commencement or the completion of the works, as the case may be.

2. The promoters of any tramway undertaking authorized by any Order, who intend to apply to the Board of Trade for a prolongation of the time limited for the commencement or the completion of the works authorized by such Order, shall publish by advertisement, once at least in each of two successive weeks, in some one and the same newspaper published in the district affected by such Order, a notice of their intention to apply to the Board of Trade for a prolongation of time.

3. The notice must state the period to which it is proposed to prolong the time limited for the commencement or the completion of the works, as the case may be, and must contain a notification that all persons desirous of making any representation to the Board of Trade, or of bringing before them any objection respecting the application, may do so by letter addressed to the Assistant Secretary (Railway Department), Board of Trade, on or before a day to

be named in the advertisement, being not less than 21 days from the date of the first publication of the advertisement, and that copies of their representations or objections should at the same time be sent to the promoters.

4. A similar notice must be delivered to every local and road authority *before* the second publication of the notice. Copies of newspapers containing the notice, and a statement that a copy of it has been duly served on the local and road authorities as required by these Rules, must be sent to the Board of Trade with the application.

5. Before the Board of Trade comply with the application, they will impose such conditions (if any) as they think fit.

III.—FORMS OF BYELAWS AND REGULATIONS ISSUED BY THE BOARD OF TRADE—

(i) FOR A LOCAL AUTHORITY.
(ii) FOR A TRAMWAY COMPANY.
(iii) WITH RESPECT TO THE USE OF STEAM POWER
(iv) WITH RESPECT TO ELECTRIC TRACTION.

(I.)

BYELAWS AND REGULATIONS MADE BY THE LOCAL AUTHORITY, UNDER SECTION 46 OF THE TRAMWAYS ACT, 1870.

1. For the purpose of these Byelaws and Regulations the term "car" shall mean any [engine or] carriage using any tramway laid down within the said [borough], and the terms "driver" and "conductor" shall respectively mean the driver and conductor or other person having charge of a [an engine or] car.

2. The driver of every car shall cause the same to be driven at a speed of not less than [four] miles an hour on the average, and not exceeding eight miles an hour.

3. The driver of every car shall so drive the same that it shall not follow a preceding car at a less distance than * yards.

4. Subject to the requirements of Byelaws Nos. 3 and 5, the driver or conductor of a car shall stop the same for the purpose of setting down or taking up passengers, when required by any passenger desiring to leave the car, or by any person desirous of travelling by the car, for whom there is room, and to whose admission no valid objection can be made: Provided that nothing in this Byelaw shall require a car to be stopped on any gradient steeper than 1 in 25.

* This distance should be not less than 10 nor more than 150 yards.

5. Except at a passing place or terminus, no car shall be stopped at the intersection or junction of two or more streets or roads, nor within [ten] yards of a car on an adjoining line of rails.

6. The driver of a car, on coming in sight of a vehicle standing or travelling on any part of the road so as not to leave sufficient space for the car to pass, shall sound his bell or whistle as a warning to the person in charge of such vehicle, and that person shall, with reasonable dispatch, cause such vehicle to be removed so as not to obstruct the car.

7. No person shall in any way wilfully impede or interfere with the traffic on the tramways, nor shall any driver or conductor needlessly cause interruption to the ordinary road traffic.

8. Every driver, conductor, or other person offending against any of these Byelaws and Regulations shall be liable to a penalty not exceeding forty shillings for each offence, and not exceeding for any continuing offence ten shillings for every day during which the offence continues.

[*Here insert any Byelaws to meet special cases.*]

9. These Byelaws shall come into force on the day of 18 .

The Common Seal of the said Mayor, Aldermen, and Burgesses, affixed by order of the Council of the said Borough at a meeting of such Council held on the day of in the presence of

Mayor.
L.S. by Town Clerk.

I hereby certify that a true copy of the foregoing Byelaws and Regulations has, in accordance with the provisions of section 46 of the Tramways Act, 1870, been laid before the Board of Trade not less than two calendar months before such Byelaws and Regulations came into operation, and that such Byelaws and Regulations have not been disallowed by the Board of Trade within the said two calendar months.

An Assistant Secretary to the Board of Trade.

day of 189 .

(II.)

BYELAWS AND REGULATIONS MADE BY THE COMPANY UNDER THE POWERS CONFERRED ON THE COMPANY BY THE TRAMWAYS ACT, 1870.

1. The Byelaws and Regulations hereinafter set forth shall extend and apply to all carriages of the Company, and to all places with respect to which the Company have power to make Byelaws or Regulations.

2. Every passenger shall enter or depart from a carriage by the hindermost or conductor's platform, and not otherwise.

3. No passenger shall smoke inside any carriage.

4. No passenger or other person shall, while travelling in or upon any carriage, play or perform upon any musical instrument.

5. A person in a state of intoxication shall not be allowed to enter or mount upon any carriage, and if found in or upon any carriage shall be immediately removed by or under the direction of the conductor.

6. No person shall swear or use obscene or offensive language whilst in or upon any carriage, or commit any nuisance in or upon or against any carriage, or wilfully interfere with the comfort of any passenger.

7. No person shall wilfully cut, tear, soil, or damage the cushions or the linings, or remove or deface any number plate, printed or other notice, in or on the carriage, or break or scratch any window of or otherwise wilfully damage any carriage. Any person acting in contravention of this Regulation shall be liable to the penalty prescribed by these Byelaws and Regulations, in addition to the liability to pay the amount of any damage done.

8. A person whose dress or clothing might, in the opinion of the conductor of a carriage, soil or injure the linings or cushions of the carriage, or the dress or clothing of any passenger, or a person who, in the opinion of the conductor, might for any other reason be offensive to passengers, shall not be entitled to enter or remain in the interior of any carriage, and may be prevented from entering the interior of any carriage, and shall not enter the interior of any carriage after having been requested not to do so by the conductor, and,

if found in the interior of any carriage, shall, on request of the conductor, leave the interior of the carriage upon the fare, if previously paid, being returned.

9. Each passenger shall, upon demand, pay to the conductor or other duly authorised officer of the Company the fare legally demandable for the journey.

10. Each person shall show his Ticket (if any) when required so to do to the conductor or any duly authorised servant of the Company, and shall also, when required so to do either deliver up his Ticket or pay the fare legally demandable for the distance travelled over by such passenger.

11. A passenger not being an artisan, mechanic, or daily labourer, within the true intent and meaning of the Acts of Parliament relating to the Company, shall not use or attempt to use any Ticket intended only for such artisans, mechanics, or daily labourers.

12. Personal or other luggage (including the tools of artisans, mechanics, and daily labourers) shall, unless otherwise permitted by the conductor, be placed on the front or driver's platform, and not in the interior or on the roof of any carriage.

13. No passenger or other person not being a servant of the Company shall be permitted to travel on the steps or platforms of any carriage, or stand either on the roof or in the interior, or sit on the outside rail on the roof of any carriage, and shall cease to do so immediately on request by the conductor.

14. No person, except a passenger or intending passenger, shall enter or mount any carriage, and no person shall hold or hang on by or to any part of any carriage, or travel therein otherwise than on a seat provided for passengers.

15. When any carriage contains the full number of passengers which it is licensed to contain, no additional person shall enter, mount, or remain in or on any such carriage when warned by the conductor not to do so.

16. When a carriage contains the full licensed number of passengers, a notice to that effect shall be placed in conspicuous letters and in a conspicuous position on the carriage.

17. The conductor shall not permit any passenger beyond the licensed number to enter or mount or remain in or upon any part of a carriage.

18. No person shall enter, mount, or leave, or attempt to enter, mount, or leave, any carriage whilst in motion.

19. No dog or other animal shall be allowed in or on any carriage, except by the permission of the conductor, nor in any case in which the conveyance of such dog or other animal might be offensive or an annoyance to passengers. No person shall take a dog or other animal into any carriage after having been requested not to do so by the conductor. Any dog or other animal taken into or on any carriage in breach of this Regulation shall be removed by the person in charge of such dog or other animal from the carriage immediately upon request by the conductor, and in default of compliance with such request may be removed by or under the direction of the conductor.

20. No person shall travel in or on any carriage of the Company with loaded fire-arms.

21. No passenger shall wilfully obstruct or impede any officer or servant of the Company in the execution of his duty upon or in connexion with any carriage or tramway of the Company.

22. The conductor of each carriage shall enforce or prevent the breach of these Byelaws and Regulations to the best of his ability.

23. Any person offending against or committing a breach of any of these Byelaws or Regulations shall be liable to a penalty not exceeding Forty Shillings.

24. The expression "conductor" shall include any officer or servant in the employment of the Company and having charge of a carriage.

25. There shall be placed and kept placed in a conspicuous position inside of each carriage in use a printed copy of these Byelaws and Regulations.

26. These Byelaws shall come into force on the day of , 189 .

Secretary of the Company.

I hereby certify that a true copy of the foregoing Byelaws and Regulations has, in accordance with the provisions of s. 46 of the Tramways Act, 1870, been laid before the Board of Trade not less than two calendar months before such Byelaws and Regulations came into operation, and that such Byelaws and Regulations have not been disallowed by the Board of Trade within the said two calendar months.

An Assistant Secretary to the Board of Trade.

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(III.)

REGULATIONS AND BYELAWS MADE BY THE BOARD OF TRADE WITH RESPECT TO THE USE OF STEAM [OR ANY MECHANICAL] POWER ON TRAMWAYS.

The Board of Trade under and by virtue of the powers conferred upon them in this behalf, do hereby order that the following Regulations for securing to the public reasonable protection against danger in the exercise of the powers conferred by Parliament with respect to the use of steam [or any mechanical] power on all or any of the tramways on which the use of such power has been authorised by the (hereinafter called "the tramways") be [added to] or [substituted for] all other Regulations in this behalf contained in any Tramway Act or Tramway Order confirmed by Act of Parliament or in any Order of the Board of Trade heretofore made thereunder:

And the Board of Trade do also hereby [make the following Byelaws] or [rescind and annul all Byelaws heretofore made by them with regard to all or any of the tramways aforesaid, and do hereby make the following Byelaws], or [in addition to the Byelaws already made by them] with regard to all or any of such tramways:—

REGULATIONS.—I. The engine or engines to be used on the tramways shall comply with the following requirements, that is to say:—

(*a*.) Each coupled wheel shall be fitted with a break block, which can be applied by a screw or treadle or by other means, and also by steam.

(*b*.) A governor (which cannot be tampered with by the driver) shall be attached to each engine, and shall be so arranged that at any time when the engine exceeds a speed of [*ten*] miles an hour it shall cause the steam to be shut off and the break applied.

(*c*.) Each engine shall be numbered and the number shall be shown in a conspicuous part thereof.

(*d.*) Each engine shall be fitted with an indicator by means of which the speed is shown; with a suitable fender to push aside obstructions; and with a special bell [or whistle, or other apparatus] to be sounded as a warning when necessary.

(*e.*) Arrangements shall be made enabling the driver to command the fullest possible view of the road before him.

(*f.*) Each engine shall be free from noise produced by blast and from the clatter of machinery such as to constitute any reasonable ground of complaint either to the passengers or to the public; the machinery shall be concealed from view at all points above four inches from the level of the rails, and all fire used on such engines shall be concealed from view.

II. Every carriage used on the tramways shall be so constructed as to provide for the safety of passengers, and for their safe entrance to, exit from, and accommodation in, such carriages, and for their protection from the machinery of any engine used for drawing or propelling such carriages.

III. The Board of Trade and their officers may, from time to time and shall on the application of the Local Authority of any of the districts through which the said tramways pass, inspect such engines or carriages used on the tramways and the machinery therein, and may, whenever they think fit, prohibit the use on the tramways of any of them which in their opinion are not safe for use.

IV. The speed at which such engines and carriages shall be driven or propelled along the tramways shall not exceed the rate of [*eight*] miles an hour, and the speed at which such engines and carriages shall pass through facing-points, whether fixed or movable, shall not exceed the rate of *four* miles an hour.

V. The engines and carriages shall be connected by double couplings.

VI. Every engine running on the tramways shall carry a lamp or lamps placed in a conspicuous position in the front of the engine, and such lamp or lamps shall be kept lighted from sunset to sunrise, or when there is a fog, and shall show when lighted a bright coloured light.

[*Here to follow any special Regulations that may be necessary.*]

VII. The speed of the engines and carriages shall not exceed the rate of *four* miles an hour at the following places :--

Penalty.—Note.—Any Company or person using steam [or any mechanical] power on the tramways contrary to any of the above Regulations is for every such offence subject to a penalty not exceeding ten pounds, and also in the case of a continuing offence to a further penalty not exceeding five pounds for every day after the first, during which such offence continues.

BYELAWS.—I. The special bell [or whistle, or other apparatus] shall be sounded by the driver of the engine from time to time when it is necessary as a warning.

II. No smoke or steam shall be emitted from the engines so as to constitute any reasonable ground of complaint to passengers or to the public.

III. Whenever it is necessary to avoid impending danger, the engine shall be brought to a standstill.

IV. The entrance to and exit from the carriages shall be by the hindermost or conductor's platform.

[*Here to follow any special Byelaws that may be necessary.*]

V. The engines and carriages shall be brought to a standstill immediately before reaching the following points :—

VI. A printed copy of the foregoing Regulations and Byelaws, and of all additional Regulations and Byelaws hereafter made, shall be placed, and kept placed, in a conspicuous position inside of each carriage in use on the tramways.

Penalty.—Note.—Any person or corporation offending against or committing a breach of any of these Byelaws is liable to a penalty not exceeding forty shillings.

The provisions of the Tramways Act, 1870, with respect to recovery of penalties is applicable to the penalties for the breach of these Regulations or Byelaws.

Signed by order of the Board of Trade this day of 189 .

An Assistant Secretary to the Board of Trade.

(IV.)

REGULATIONS MADE BY THE BOARD OF TRADE UNDER THE PROVISIONS OF THE TRAMWAYS ACT, FOR REGULATING THE EMPLOYMENT OF INSULATED RETURNS, OR OF UNINSULATED METALLIC RETURNS OF LOW RESISTANCE; FOR PREVENTING FUSION OR INJURIOUS ELECTROLYTIC ACTION OF OR ON GAS OR WATER PIPES OR OTHER METALLIC PIPES, STRUCTURES, OR SUBSTANCES: AND FOR MINIMISING AS FAR AS IS REASONABLY PRACTICABLE INJURIOUS INTERFERENCE WITH THE ELECTRIC WIRES, LINES, AND APPARATUS OF PARTIES OTHER THAN THE COMPANY, AND THE CURRENTS THEREIN, WHETHER SUCH LINES DO OR NOT USE THE EARTH AS A RETURN.

DEFINITIONS.—In the following regulations—The expression "energy" means electrical energy. The expression "generator" means the dynamo or dynamos or other electrical apparatus used for the generation of energy. The expression "motor" means any electric motor carried on a car and used for the conversion of energy. The expression "pipe" means any gas or water pipe or other metallic pipe, structure, or substance. The expression "wire" means any wire or apparatus used for telegraphic, telephonic, electrical signalling or other similar purposes. The expression "current" means an electric current exceeding one-thousanth part of one ampere. The expression "The Company" has the same meaning as in the Tramways Act.

REGULATIONS.—1. Any dynamo used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation.*

2. One of the two conductors used for transmitting energy from

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* The Board of Trade will be prepared to consider the issue of regulations for the use of alternating currents for electrical traction on application.

the generator to the motors shall be in every case insulated from earth, and is hereinafter referred to as the "line"; the other may be insulated throughout, or may be uninsulated in such parts and to such extent as is provided in the following regulations, and is hereinafter referred to as the "return."

3. Where any rails on which cars run or any conductors laid between or within three feet of such rails form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated, unless of such sectional area as will reduce the difference of potential between the ends of the uninsulated portion of the return below the limit laid down in Regulation 7.

4. When any uninsulated conductor laid between or within three feet of the rails forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 feet by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity.

5. When any part of a return is uninsulated it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected, through the current-indicator hereinafter mentioned, to two separate earth connections which shall be placed not less than 20 yards apart.

Provided that in place of such two earth connections the Company may make one connection to a main for water supply of not less than three inches internal diameter, with the consent of the owner thereof and of the person supplying the water, and provided that where, from the nature of the soil or for other reasons, the Company can show to the satisfaction of an inspecting officer of the Board of Trade that the earth connections herein specified cannot be constructed and maintained without undue expense the provisions of this regulation shall not apply.

The earth connections referred to in this regulation shall be constructed, laid, and maintained so as to secure electrical contact with the general mass of earth, and so that an electro-motive force, not exceeding four volts, shall suffice to produce a current of at least two amperes from one earth connection to the other through the earth, and a test shall be made at least once in every month to ascertain whether this requirement is complied with.

No portion of either earth connection shall be placed within 6 feet of any pipe except a main for water supply of not less than 3 inches internal diameter which is metallically connected to the earth connections with the consents hereinbefore specified.

6. When the return is partly or entirely uninsulated the Company shall in the construction and maintenance of the tramway (*a*) so separate the uninsulated return from the general mass of earth, and from any pipe in the vicinity; (*b*) so connect together the several lengths of the rails; (*c*) adopt such means for reducing the difference produced by the current between the potential of the uninsulated return at any one point and the potential of the uninsulated return at any other point; and (*d*) so maintain the efficiency of the earth connections specified in the preceding regulations as to fulfil the following conditions, viz:—

(i.) That the current passing from the earth connections through the indicator to the generator shall not at any time exceed either two amperes per mile of single tramway line or five per cent. of the total current output of the station.

(ii.) That if at any time and at any place a test be made by connecting a galvanometer or other current-indicator to the uninsulated return and to any pipe in the vicinity, it shall always be possible to reverse the direction of any current indicated by interposing a battery of three Leclanché cells connected in series if the direction of the current is from the return to the pipe, or by interposing one Leclanché cell if the direction of the current is from the pipe to the return.

In order to provide a continuous indication that the condition (i) is complied with, the Company shall place in a conspicuous position a suitable, properly connected, and correctly marked current-indicator, and shall keep it connected during the whole time that the line is charged.

The owner of any such pipe may require the Company to permit him at reasonable times and intervals to ascertain by test that the conditions specified in (ii) are complied with as regards his pipe.

7. When the return is partly or entirely uninsulated a continuous record shall be kept by the Company of the difference of potential during the working of the tramway between the points of the uninsulated return furthest from and nearest to the generating station. If at any time such difference of potential exceeds the limit of seven volts, the Company shall take immediate steps to reduce it below that limit

8. Every electrical connection with any pipe shall be so arranged as to admit of easy examination, and shall be tested by the Company at least once in every three months.

9. Every line and every insulated return or part of a return except any feeder shall be constructed in sections not exceeding one-half of a mile in length, and means shall be provided for isolating each such section for purposes of testing.

10. The insulation of the line and of the return when insulated, and of all feeders and other conductors, shall be so maintained that the leakage current shall not exceed one-hundredth of an ampere per mile of tramway. The leakage current shall be ascertained daily before or after the hours of running when the line is fully charged. If at any time it should be found that the leakage current exceeds one-half of an ampere per mile of tramway the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within twenty-four hours. Provided that where both line and return are placed within a conduit this regulation shall not apply.

11. The insulation resistance of all continuously insulated cables used for lines, for insulated returns, for feeders, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of ten megohms for a length of one mile. A test of the insulation resistance of all such cables shall be made at least once in each month.

12. Where in any case in any part of the tramway the line is erected overhead and the return is laid on or under the ground, and where any wires have been erected or laid before the construction of the tramway in the same or nearly the same direction as such part of the tramway, the Company shall, if required so to do by the owners of such wires or any of them, permit such owners to insert and maintain in the Company's line one or more induction-coils or other apparatus approved by the Company for the purpose of preventing disturbance by electric induction. In any case in which the Company withhold their approval of any such apparatus the owners may appeal to the Board of Trade, who may, if they think fit, dispense with such approval.

13. Any insulated return shall be placed parallel to and at a distance not exceeding three feet from the line when the line and return are both erected overhead, or eighteen inches when they are both laid underground.

14. In the disposition, connections, and working of feeders the Company shall take all reasonable precautions to avoid injurious interference with any existing wires.

15. The Company shall so construct and maintain their system as to secure good contact between the motors and the line and return respectively.

16. The Company shall adopt the best means available to prevent the occurrence of undue sparking at the rubbing or rolling contacts in any place and in the construction and use of their generator and motors.

17. In working the cars the current shall be varied as required by means of a rheostat containing at least twenty sections, or by some other equally efficient method of gradually varying resistance.

18. Where the line or return or both are laid in a conduit the following conditions shall be complied with in the construction and maintenance of such conduit:—

(*a.*) The conduit shall be so constructed as to admit of easy examination of and access to the conductors contained therein and their insulators and supports.

(*b.*) It shall be so constructed as to be readily cleared of accumulation of dust or other *débris*, and no such accumulation shall be permitted to remain.

(*c.*) It shall be laid to such falls and so connected to sumps or other means of drainage, as to automatically clear itself of water without danger of the water reaching the level of the conductors.

(*d.*) If the conduit is formed of metal, all separate lengths shall be so jointed as to secure efficient metallic continuity for the passage of electric currents. Where the rails are used to form any part of the return they shall be electrically connected to the conduit by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or other means of equal conductivity, at distances apart not exceeding one hundred feet. Where the return is wholly insulated and contained within the conduit, the latter shall be connected to earth at the generating station through a high-resistance galvanometer suitable for the indication of any contact or partial contact of either the line or the return with the conduit.

(*e.*) If the conduit is formed of any non-metallic material not being of high insulating quality and impervious to moisture throughout, and is placed within six feet of any pipe, a non-conducting screen shall be interposed between the conduit and the pipe, of such material and dimensions as shall provide that no current can pass between them without traversing at least six feet of earth, or the circuit itself shall in such case be lined with bitumen or other non-conducting damp-resisting material in all cases where it is placed within six feet of any pipe.

(*f.*) The leakage current shall be ascertained daily, before or after the hours of running when the line is fully charged, and if at any time it shall be found to exceed half an ampere per mile of tramway the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within twenty-four hours.

19. The Company shall, so far as may be applicable to their system of working, keep records as specified below. These records shall, if and when required, be forwarded for the information of the Board of Trade.

DAILY RECORDS.—No. of cars running.
Maximum working current.
Maximum working pressure.
Maximum current from the earth connections (*vide* Regulation 6 (i.)).
Leakage current (*vide* Regulations 10 and 18 (*f.*)).
Fall of potential in return (*vide* Regulation 7).

MONTHLY RECORDS.—Condition of earth connections (*vide* Regulation 5).
Insulation resistance of insulated cables (*vide* Regulation 11).

QUARTERLY RECORDS.—Conductance of joints to pipes (*vide* Regulation 8).

OCCASIONAL RECORDS.—Any tests made under provisions of Regulation 6 (ii.).
Localisation and removal of leakage, stating time occupied.
Particulars of any abnormal occurrence affecting the electric working of the tramway.

6th March, 1894.

Board of Trade,
7, Whitehall Gardens, S.W.

IV.—PARLIAMENTARY ENACTMENTS AS TO SCOTLAND AND IRELAND.

SCOTLAND.

THERE is a special Act—the Tramways (Scotland) Act, 1861 (24 & 25 Vict. c. 69)—applying only to Scotland, by which facilities were given for the construction of tramways in country districts (namely, on "turnpike and statute labour roads"), but practically none for their construction in large towns. Even as regards country districts, however, the Act has remained a dead letter. The Tramways Act, 1870 (*ante*, pp. 665 to 672), applies to Scotland as well as England, and since the date of its passing, all tramways constructed in Scotland have accordingly been subject to its provisions, which (as will have been seen) afford the fullest facility for the construction of tramways in towns.

IRELAND.

In Ireland, the Act of 1870 does not apply, there being a number of Acts applicable to Ireland alone. The proceedings under these Acts, although not as uniform as in England under the single Act of 1870, are of a simple character.

The Acts relating to tramways are the Tramways (Ireland) Act, 1860 (23 & 24 Vict. c. 152); the Tramways Ireland (Amendment) Act, 1861 (24 & 25 Vict. c. 102); the Act of 1871, known as Lord Cairns's Act (34 & 35 Vict. c. 114); the amending Act of 1876 relating only to Dublin (39 & 40 Vict. c. 65); the Tramways (Ireland) Amendment Act, 1881 (44 & 45 Vict. c. 17); and the Tramways and Public Companies (Ireland) Act, 1883 (46 & 47 Vict. c. 43).

The course of procedure under the Acts is as follows: "The promoters present a memorial to the Lord Lieutenant in Council, setting forth the particulars of their scheme, and stating that the requirements of the Acts as to notice, &c., have been complied with; and to the memorial is appended a draft of the proposed Order. A public inquiry is then made by the Board of Works as to the merits of the undertaking in an engineering point of view, and the grand jury of the county, after considering the report of the Board of Works and other matters, provisionally approve or disapprove of the undertaking. Provision is made for traversing their decision on the grounds either that the preliminaries required by law have not been complied with, or that the construction of the undertaking according to the plan approved of by them would not be beneficial to the public. An appeal is reserved to the Lord Lieutenant, who has a discretion as to making an Order or not.

"The Order is not required to be confirmed by Parliament in cases where the undertaking is approved by the grand jury and no petition of appeal against such approval has been presented to the Lord Lieutenant; but in any case in which an appeal has been presented before the Order in Council is made, the Order has no effect until confirmed by Parliament, even although no person shall appear on such appeal.

"The authorised gauge is five feet three inches, being the ordinary railway gauge in Ireland." *

Lord Cairns's Act of 1871 provided for the introduction of steam as a motive power, subject to a restriction to a speed of six miles an hour on country roads, and three miles an hour in towns or villages (the latter restriction pointing, no doubt, to the use of steam for mineral rather than for passenger traffic); but by the Act of 1881 a speed of six miles an hour was allowed in towns or villages, and a speed of ten miles on country roads.

By a separate set of Acts relating to "light railways" in Ireland, provision has been made for aid from the Treasury in cases where it is declared by the Lord Lieutenant of Ireland in Council that it is desirable that a light railway should be constructed for the development of fisheries or other industries; and it is declared that the expression "light railway" includes "tramway" as that word is used in the Tramway (Ireland) Acts (52 & 53 Vict. c. 66, § 11). The proceedings to be taken for the establishment of light railways are similar to those in the case of tramways, subject, however, to the special provisions of the Acts dealing with light railways. These are the Light Railways (Ireland) Act, 1889 (52 & 53 Vict. c. 66); the Railways (Ireland) Act, 1890 (53 and 54 Vict. c. 52); Transfer of Railways (Ireland) Act, 1890 (54 Vict. c. 2); and the Public Accounts and Charges Act, 1891 (54 & 55 Vict. c. 24).

By the Act of 1890, it was provided that the promoters of any undertaking, who have obtained from a grand jury a presentment under the Tramways (Ireland) Acts approving of their undertaking, may enter into an agreement with any railway company with whose railway the undertaking is or is intended to be connected, for the transfer of the undertaking to the railway company. But any such agreement requires the sanction of the shareholders of the railway company and the approval of the Railway and Canal Commission. (54 Vict. c. 2, §§ 1—3.)

* Sutton's *Tramway Acts of United Kingdom* (2nd ed., 1883), pp. li., lii.

V.—TERMS OF PURCHASE OF TRAMWAYS BY LOCAL AUTHORITIES (JUDGMENT OF THE HOUSE OF LORDS).

JUDGMENT was given by the House of Lords, determining the interpretation to be put on certain provisions of the Tramways Act, 1870, on 30th July, 1894. Two cases were before the House on appeal—in the one case from the Scotch Courts, and in the other case from the English Courts—the main question being the same in each case—namely, upon what principle the sum to be paid by a Local Authority for the purchase of a line of tramway, under the provisions of the 43rd section of the Act of 1870, is to be calculated. Section 43 of the Tramways Act, 1870, is as follows:—

> "Where the promoters of a tramway in any district are not the local authority, the local authority, if, by resolution passed at a special meeting of the members constituting such local authority, they so decide, may within six months after the expiration of a period of twenty-one years from the time when such promoters were empowered to construct such tramway, and within six months after the expiration of every subsequent period of seven years, or within three months after any order made by the Board of Trade under either of the two next preceding sections, with the approval of the Board of Trade, by notice in writing require such promoters to sell, and thereupon such promoters shall sell to them their undertaking, or so much of the same as is within such district, upon terms of paying the then value (exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory sale, or other consideration whatsoever) of the tramway, and all lands, buildings, works, materials, and plant of the promoters suitable to and used by them for the purposes of their undertaking within such district, such value to be in case of difference determined by an engineer or other fit person nominated as referee by the Board of Trade on the application of either party, and the expenses of the reference to be borne and paid as the referee directs. And when any such sale has been made, all the rights, powers, and authorities of such promoters, in respect to the undertaking sold, or where any order has been made by the Board of Trade under either of the next preceding sections, all the rights, powers, and authorities of such promoters, previous to the making of such order in respect to the undertaking sold, shall be transferred to, vested in, and may be exercised by the authority to whom the same has been sold, in like manner as if such tramway was constructed by such authority under the powers conferred upon them by a provisional order under this Act, and in reference to the same they shall be deemed to be the promoters."

The subjoined report of the two cases is taken (in substance) from the *Times* of July 31st, 1894:—

HOUSE OF LORDS (JULY 30, 1894).

(*Before the* LORD CHANCELLOR, LORD WATSON, LORD ASHBOURNE, *and* LORD SHAND).

THE EDINBURGH STREET TRAMWAYS COMPANY *v.* THE LORD PROVOST, MAGISTRATES, &C., OF THE CITY OF EDINBURGH.

This was an appeal by the above-mentioned tramway company from a decision of the First Division of the Court of Session in Scotland, the respondents being the local authority within the City of Edinburgh entitled by section 43 of the Tramways Act, 1870, to purchase the tramway undertaking within their district on the expiration of twenty-one years from the time when it was authorised to be constructed.

On the 12th of August, 1892, they gave notice to the appellants that, in exercise of their rights under the section, they would purchase the appellants' undertaking within the City of Edinburgh (except the line from Waterloo Place to Jock's Lodge), twenty-one years having elapsed since the appellants' tramway was authorised. The appellants and respondents having differed as to the price to be paid for the undertaking, the Board of Trade, on November 15th, 1892, appointed Mr. Henry Tennant, of York, as referee, to fix what the said price should be.

Mr. Tennant having heard proof on behalf of both parties, including evidence for the appellants as to the rental value of, or owners' interest in, the tramway lines which the respondents were purchasing, on November 13th, 1893, he issued his award, finding the appellants entitled to £212,979 7s. 6d. for the various items which were being sold by them to, and which had to be paid for by, the respondents.

In setting out award, Mr. Tennant stated that the following questions arose in the course of the proof and argument :—

> "(Second), Whether in view of the terms of said section 43 of said Tramways Act of 1870, I am entitled, in valuing tramways, to take into account the present profits or rental value of the undertaking, or on what other basis the value of said tramways should be determined; and (Third) whether, in the event of the basis of valuation of said tramways being found to be according to the cost of construction and establishment, I am entitled in said valuation to make allowance to said company for certain sums expended by said company in obtaining Parliamentary authority for the construction thereof, and for a sum of £2,500 contributed by said company towards the cost of widening the North Bridge in the City of Edinburgh."

Mr. Tennant went on to say :—

> "And, considering that, to enable me, as referee under said appointment by the Board of Trade, to proceed to the proper and complete determination of the value of the said tramways, lands, buildings, and others, I have found it

> necessary, in the first place, to dispose of the said questions which have arisen as aforesaid, and that, after full consideration of said questions, and specially after careful consideration of the terms of said section 43 of said Tramways Act of 1870, I am of opinion that I must assume. . . . . (Second) That in valuing the tramways I am not entitled to take into account the present profits or rental value of the undertaking, but that the proper value of said tramways to be determined by me, according to my construction of the statute is such sum as it would cost to construct and establish the same under deduction of a proper sum in respect of depreciation to their present condition, and that in estimating such cost I am entitled to take into account the fact that said tramways are now successfully constructed and in complete working condition: (Third) that I am entitled, in valuing said tramways according to cost of construction and establishment, to make allowance both for the sums expended by said company in obtaining said Parliamentary authority, in so far as I consider such expenditure necessary or proper, and also for the said sum of £2,500 which sum I consider was a necessary and proper expenditure by said company to enable double lines of tramways to be laid over said North Bridge, and which double lines form part of the undertaking."

Action was taken by the tramway company for the purpose of reducing the said award or degree-arbitral, on the ground that Mr. Tennant's view of the 43rd section of the Tramways Act was erroneous; and for declarator that he ought, under that section, to have fixed the value to be paid by the Corporation of Edinburgh for the tramway on a rental basis, and for an order on him to proceed with the reference, and to find and declare the value of the tramway lines according to their rental value. Both the Lord Ordinary and the First Division (the Lord President dissenting), in the Court of Session, held Mr. Tennant's award to be good and his view of the 43rd section of the Tramways Act to be correct, and repelled the appellants' pleas, sustained the defences, and assoilzied the respondents. The appellants thereupon brought the present appeal.

Mr. Asher, Q.C., Mr. A. Graham Murray, Q.C., and Mr. Vary Campbell, appeared for the company; and the Lord Advocate and Mr. Moulton, Q.C., for the Edinburgh Corporation; and when the case was argued some time ago, judgment was reserved.

Their Lordships now delivered judgment, from which it will be seen that the decision of the Court below in favour of the respondents was affirmed by a majority, Lord Ashbourne dissenting.

The LORD CHANCELLOR.—The appellant company was formed under the provisions of a private Act of Parliament in the year 1871. This Act incorporated Part II. and Part III. of the Tramways Act, 1870. Section 43 of that Act entitled the respondents within six months after the expiration of a period of twenty-one years from the time when the appellants were empowered to construct the tramway by notice in writing to require the appellants to sell their undertaking. They accordingly, on August 12th, 1892, gave notice to the appellants that in exercise of their rights under that section they would purchase the appellants' undertaking within the city of Edinburgh.

The appellants and respondents having differed as to the price to be paid, the Board of Trade appointed Mr. Henry Tennant, of York, as referee, to fix what the price should be. In the narrative of the award or degree-arbitral, which he made, Mr. Tennant stated that, in his opinion, after careful consideration of the terms of section 43 of the Tramways Act, 1870, in valuing the tramways he was not entitled to take into account the present profits or rental value of the undertaking, but that the proper value of the tramways to be determined by him, according to his construction of the statute, was such sum as it would cost to construct and establish the same under deduction of a proper sum in respect of depreciation for their present condition, and that in estimating such cost he was entitled to take into account the fact that the tramways were then successfully constructed and in complete working condition.

The present action was thereupon raised by the appellants against the respondents for the purpose of reducing Mr. Tennant's award or decree-arbitral, upon the ground that his view of section 43 of the Tramways Act, 1870, was erroneous, and for declarator that he ought, under the section, to have fixed the value to be paid by the respondents for the tramways upon the rental basis, and for an order on him to proceed with the reference, and to find and declare the value of the tramway lines according to their rental value. Both the Lord Ordinary and the First Division of the Inner House have held Mr. Tennant's award to be good, and have assoilzied the respondents. The question on this appeal is whether these decisions were correct.

The question turns on the construction to be put upon the language employed in section 43 of the Tramways Act, 1870, which prescribes the terms upon which the promoters of a tramway (in this case the appellants) are to sell their undertaking to the local authority. The words are as follows:—"Upon terms of paying the then value (exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory sale, or other consideration whatsoever) of the tramway and all lands, buildings, works, materials, and plant of the promoters suitable to and used by them for the purposes of their undertaking."

It is contended on behalf of the appellants that the value of the tramway must be ascertained by taking into consideration what rental could be obtained for it if let with all the statutory rights of using it possessed by the promoters, and then allowing whatever may be thought the proper number of years' purchase of the rental which could thus be obtained. The sum so arrived at, it was argued, would represent the then value of the tramway within the meaning of the section. Before discussing the language used by the Legislature, it is, I think, necessary to consider the nature of the rights and powers of the promoters which it is said are to be thus taken into account, and the manner in which they are conferred upon them. The promoters obtained authority, in the first place, to interfere with public highways by laying down tramways upon them, and maintaining the tramways so laid down. But the most important power which they obtained was that contained in section 34 of the Tramways Act, 1870, which authorised them to use upon the tramways so laid down carriages with flanged wheels, or wheels suitable only to run on the rail prescribed by their Act, and provided that subject to the provisions of their Special Act and of that Act the promoters and their lessees should have the exclusive use of their tramways for carriages with flanged wheels or other wheels suitable only to run on the prescribed rail. It will be seen that the power thus conferred is limited to the promoters and their lessees, the promoters being the person or company authorised to construct the tramways. The right conferred is a personal one, and cannot be claimed by any persons who do not come within the designation of promoters or lessees of promoters. It is not conferred upon the promoters' assignees. A conveyance, therefore, by the promoters of their tramways, or even of their undertaking, would not carry with it the right to the statutory monopoly conferred upon the promoters by the section to which I have referred.

I proceed now to consider the words of the provision upon which the question at issue turns. It is to be observed that, although the undertaking is described as the subject of the sale, it is to be sold, not upon terms of paying its then value, but upon terms of paying "the then value of the tramway and all lands, buildings, works, material, and plant of the promoters suitable to and used by them for the purposes of their undertaking." It appears clear that the word "tramway" cannot be read as synonymous with "undertaking." The words which follow "tramway" are, to my mind, conclusive upon this point. What, then, does "tramway" mean as used in the section? I have examined every instance of its use in the statute, and it appears to me in every other case, at all events, to be used to describe the structure laid down on the highway, and nothing more, and I cannot see my way to give any other meaning to it in the section under consideration. The word "tramway" may, no doubt, without impropriety be held to include all proprietary rights attached to it; but I do not think that it can with propriety be held to compromise all the powers in relation to the tramway which are conferred by the statute upon the promoters. I have already pointed out that the power exclusively to use the tramway was granted to the promoters as such, and is not capable of transfer by them. This is distinctly recognised by the enactment which immediately follows that under consideration. It is provided that when a sale has been made, all the rights, powers, and authorities of the promoters in respect to the undertaking sold shall be transferred to, vested in, and may be exercised by the authority to whom the same has been sold in like manner as if the tramway was constructed by such authority under the powers conferred upon them by a provisional order under the Act, and in reference to the same they shall be deemed to be the promoters. It is by virtue of this enactment, and of this alone, that the local authority become entitled to the exclusive use of the tramway, which was previously vested in the promoters. It is the statute, and not the company which originally constructed the tramways, which confers upon the local authority this right. It is also worthy of note that some, if not all, of the rights, powers, and authorities of the promoters are treated as not included even in the term "undertaking," inasmuch as they are spoken of as the rights, powers, and authorities of the promoters "in respect to the undertaking sold."

I have so far dealt with the language of the section, without taking into consideration the words within the parenthesis, upon which so much of the argument turned; what was to be paid by the purchasers was the then value of the tramway, "exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory sale or other consideration whatsoever."

It was contended for the appellants that the presence of the parenthesis indicated that in the opinion of the Legislature the term "value of the tramway" would, but for the words in the parenthesis, have justified an allowance for past or future profits of the undertaking, and must therefore include something more than the value of the structure. I cannot assent to this argument. The words of the parenthesis may well have been enacted by way of precaution to make sure that countenance was not given to any contention which would have involved fixing a sum in excess of the value of the structure. There is, I think, a fallacy involved in considering the meaning of the words which follow the parenthesis by themselves, and then inquiring how far the meaning thus attributed to them is to be modified by reason of the words which precede. Each part of the provision throws light on the other. It is by reading it as a whole that the intention of the Legislature is to be ascertained. The words found within the parenthesis, to my mind, support the view that "tramway" is to be construed in the manner which I have indicated, and not in that contended for by the appellants.

It is said that the words "exclusive of any allowance for past or future profits of the undertaking" were introduced for the purpose of preventing the arbitrator making any addition to the value otherwise arrived at in respect of such profit. I find it difficult to understand how it could ever be supposed that an arbitrator would make any addition to the value of the tramway in respect of the past profits of the undertaking, or how it could ever have been thought necessary to prohibit his doing so. It is, however, quite intelligible that it might be thought necessary to guard against his allowing for, or, in other words, taking into account, past profits in arriving at the value of the tramway. But if the word "allowance" is used in this sense in relation to past profits, its meaning must be the same in relation to future profits. I, therefore, construe the words as enacting that neither the profits made in the past nor to be anticipated in the future were to be taken into account in assessing the value.

It was argued that if the value of the tramway were arrived at by taking so many years' purchase of the rental which could have been obtained for it, if let, no profits would be allowed for in the value so ascertained. I am unable to adopt this view. How would it be possible to determine the rental which could be obtained except by reference to the profits which had been or which might be made? The rent which a tenant would be prepared to give would obviously depend upon the profits to be anticipated. It was further argued that the Legislature had only excluded an allowance for past or future and not for present profits. Why, it was asked, if all profits were to be excluded, were the words "past or future" inserted? To my mind the words cover all profits, whether made or to be made. And the reason for their insertion appears to me plain. If the word "profits" alone had been used it would have been open to contention that only profits actually made were referred to, and that the provision did not exclude an allowance for profits to be anticipated in the future. Reading the enactment as a whole, I can find no indication, but quite the contrary, that the arbitrator, in determining the then value of the tramway, was to take into account those rights and powers which had been possessed by the promoters as such by virtue of the statute, and which would be thereafter by the said statute conferred upon the local authority.

Reliance was placed by the appellants upon the provisions of sections 41 and 42 of the Tramways Act, 1870, enabling the Board of Trade, if the promoters discontinued the working of their tramway, or were insolvent, to declare that their powers in respect of the tramway should be at an end. In the first of these cases, the Board of Trade were empowered to declare the powers of the promoters at an end from the date of the order, in the latter, at the expiration of six months from the making of the order, but in both cases it is provided that the powers of the promoters shall thereupon cease and determine, "unless the same are purchased by the local authority in manner by this Act provided." Inasmuch as section 43 applies to a purchase by the local authority within three months after any order made by the Board of Trade under either of the two preceding sections, it was contended that this showed that the purchase of the undertaking was regarded by the Legislature as a purchase of the powers of the promoters.

I do not think it possible to give the effect contended for to this argument, and to construe the word "tramway" in that part of section 43 which regulates the terms of payment in a different manner to that which a consideration of the section itself suggests on account of the language employed in the two preceding sections. That language is certainly not very felicitous. Whether the undertaking is purchased or not, the powers of the promoters equally cease and determine: the purchase does not keep their statutory powers alive. The powers are possessed thereafter by the local authority by virtue of the statute, in precisely the same manner as they were acquired by the promoters.

For these reasons I think the interlocutors appealed from should be affirmed, and the appeal dismissed with costs.

LORD WATSON and LORD SHAND concurred.

LORD ASHBOURNE.—The facts of the case have been so fully stated by the Lord Chancellor, that I need only refer to them at such length as may make my meaning plain.

The direct question raised before your Lordships is, whether the arbitrator was right in valuing the tramway at what it would cost to make, or whether he ought to have ascertained what it could have been let for to a tenant who could use it, and then have capitalised its annual value.

The cases of the Edinburgh Street Tramways Company and of the London Street Tramways Company [see *post*] have been argued before your Lordships together, as they depend upon precisely the same point. The question in the Edinburgh case depends upon the construction of section 43 of the general Tramways Act, 1870, and the London case depends upon section 44 of the London Street Tramways Act, but the two sections are in identical terms, as is the case with many other sections of the Act. For convenience, I shall refer only to the sections of the general Tramways Act, 1870, and shall not deem it necessary to note specially the corresponding sections of the London Street Tramways Act of 1870, which are mentioned in detail in the judgments in the London case.

The decision your Lordships are now called on to give is of deep moment to all the tramway companies in Great Britain, and involves interests of considerable magnitude. The section is not clear. In any view of the case it is a cumbrous and unfortunate piece of drafting, not plain or direct, and each side is confronted with difficulties in its interpretation. It is not surprising to find that amongst the Judges before whom the case has come there have been wide differences of opinion, and therefore I have applied myself to the consideration of the case, with many doubts and misgivings as to the soundness of my own judgment on important points, where, though I might be supported by the opinions of Judges of eminence, I know my conclusions have been opposed to authorities for whom I entertain the very highest respect. The clause requires the closest and most critical examination and analysis in order to see what is the method of the transfer, what is sold, and what is to be paid.

What is the method? As *Mr. Justice Mathew*, in the London case, has forcibly said, "Nothing would have been easier than to have said that at the end of the twenty-one years there shall be a transfer of your undertaking, and you shall be paid for the cost of material *in situ* capable of being worked, less depreciation." But the Legislature in its wisdom has used a long, complicated, and involved sentence, from which we have to spell out and infer such meanings as we can. The transaction is to take place by a sale. A sale involves a selling and a buying, a bargaining, and here an arbitration. If what was meant was a statutable transfer at a statutable price, it was certainly not felicitous drafting to enact that the transaction should be carried out by the machinery set out at such length in the section. But a far more important consideration in the matter is what is sold and transferred under the section. The undertaking, of course, is sold, but the great difficulty is to give the due and proper meaning to the word "tramway." Is it only the tramway *in situ*, or the tramway with the power to use it? This is really a governing point in the case. Does the sale of the tramway include or involve or carry with it the right to use it? The words of the section are, "When any such sale has been made, all the rights, powers, and authorities of the company in respect of the undertaking sold . . .

shall vest" in the purchaser. The words here, again, are not the best or the clearest. They must be read, not only with the rest of the section, but also in connection with other sections, in order to see whether the right to the tramway is treated in the Act as carrying with it the right to use the tramway.

Section 41 deals with the discontinuance of tramways, and enacts that in certain cases the Board of Trade may by order declare that from the date of the order the powers of the promoters shall be at an end, "and the said powers of the promoters shall cease and determine, unless the same are purchased by the local authority in manner by this Act provided"—*i.e.*, by section 43. Thus section 41 expressly states that the powers, including the right to use, are purchased under section 43.

Section 42 is to the like effect. It deals with the insolvency of promoters, and provides for the ceasing of their powers "unless the same are purchased by the local authority in manner by this Act provided," *i.e.*, again by section 43.

In this connection it is important to note section 44, which enacts,—

> "Where any tramway in any district has been opened for traffic for a period of six months, the promoters may, with the consent of the Board of Trade, sell their undertaking to any person, corporation, or company, or to the local authority of such district; and when any such sale has been made, all the rights, powers, authorities, obligations, and liabilities of such promoters in respect to the undertaking sold shall be transferred to, vested in, and may be exercised by, and shall attach to the person, corporation, company, or local authority to whom the same has been sold, in like manner as if such tramway was constructed by such person, corporation, company, or local authority under the powers conferred upon them by special Act, and in reference to the same they shall be deemed to be the promoters."

In my opinion a sale under section 44 would carry with it the right to use the tramway. Similar words are used in section 43; the machinery of sale is resorted to, "the rights, powers, and authorities" are also transferred, and I cannot resist the conclusion that under both sections the buyer was intended to purchase and acquire with the tramway the right to use it.

It was argued before your Lordships that the powers were to be regarded as the creatures of the statute, given independently by its provisions to "the promoters," and that the sale had nothing to say to them, and did not carry, affect, or transfer them. I do not find any such idea in the judgments of the Court of Appeal in the London case. *Lord Justice Lindley* says, "The vendors have only a right of user, that is by section 20; they have no land to sell, they have only an easement so far as the land is concerned, but they have an exclusive right to use the tramway by section 29, and to grant licences to other persons to use it by section 37. These rights will be enjoyed by the purchasers, and these rights must be borne in mind in ascertaining the value of the tramway. These rights exclude any valuation of the tramway as so much old iron to be broken up and removed. The tramway must be valued as an existing tramway, used as such by the vendors before the sale, and to be used as such by the purchasers after the sale."

The words of *Lord Justice Smith* on this point are very strong and clear: "I cannot doubt that what is to be sold and bought is not merely the tramway *in situ* as a structure, but the undertaking of the company as a going, toll-earning concern—that is to say, the tramway as then in use, with the rights, powers, and authorities of the company to maintain it in the public streets, run cars thereon with flanged wheels to the exclusion of all others, to take the prescribed tolls for so doing, and to exercise the other powers contained in the Act. Of this I have no doubt; the words of the section are clear, 'and thereupon the company shall sell,' not their rails and sleepers, but 'their undertaking,' and when such sale has been made, 'all the rights, powers, and authorities of the company in respect to the undertaking are to vest in the County Council.'"

Lord Justice Smith, in the clearest words, gave his opinion that the company had to sell "the powers granted to the company of running cars with flanged wheels thereon to the exclusion of all others, and of taking the prescribed tolls and the other powers in the Act mentioned"; and he adds emphatically, "that this is what is to be sold by the company to the London County Council I do not doubt."

I concur in this view of Lord Justice Smith, which I regard as of the highest importance as stating and explaining the great value of the subject-matter to be sold. It may be that the language of the section is involved and roundabout, that the conveyancing is defective; but to my mind it is much more in accordance with the language of all the sections of the Act to hold the conclusion I have indicated than to spell out a narrower one in contradiction to what I believe to be the meaning of section 43 itself, as well as to the clear words of sections 41 and 42, and the construction required to give effect to section 44.

If, then, the undertaking sold comprised or included a tramway capable of being used and with a right to use it, the next great question is, What is the price to be paid for it under the section? The section answers (leaving out the parenthesis for the present), "the then value of the tramway, and all lands, buildings, works, materials, and plant." The actual tramway, in a very literal sense, consists of little else except its iron rails. The then value of the tramway from the old iron point of view, would be a ludicrous mockery, and accordingly every one—Judges and arbitrators alike—repudiate any such construction, and admit that a wider interpretation must be sought. *Lord Justice Smith* says: "There can be no doubt that in any ordinary case, where an undertaking, such as the present, is to be sold and paid for, its present—that is, its then value is in practice arrived at by capitalising its rental value." *Mr. Justice Mathew* on this point says: "Value is to be ascertained as it would have to be ascertained where, for instance, the property was rated, and, therefore, you must use it in its proper sense. This tramway is a hereditament, capable of earning profits, and assessable under the Poor Law Act. In arriving at its value, it is clear from the Pimlico case (9 L.R.Q.B.) that the meaning of the word value is recognised in many cases in *pari materiâ* statutes, for instance, relating to metropolitan valuation in the Act of 1869, and also in the Union Assessment Act. To get at the value you take the profits, deduct the tenants' charges and profits, and what is left is the rent which would be paid by a tenant for the opportunity of earning his profit, and which would be earned by the occupier, who is the tenant. That is the rent, and by capitalising that rental you get at the value of the hereditament."

I therefore take it that apart from the parenthesis "the then value" would be held to have its ordinary meaning, as stated by Lord Justice Smith. The onus of proving that the ordinary meaning should not be given to the words "the then value" is cast upon those who deny it, and the respondents insist that for this purpose they are entitled to rely upon the parenthesis, which says "exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory sale or other considerations whatsoever." *Primâ facie*, these words imply that, but for their use, the thing excluded would have been included. An exception, a parenthesis, an exclusion, under ordinary circumstances, would be held to qualify and lessen the generality of preceding words. Here, according to the contention, they are used not to abate, but to destroy and contradict, the ordinary meaning of the words, "the then value."

If the argument is correct that the value of the tramway is only the value of the materials *in situ*, profits would not need to be excluded, because not comprised in the original subject-matter. It is admitted that "the then value" is not to be found in the value of old iron; it is admitted that something very much more is to be assessed. Where is the line to be drawn? Lord Justice Smith well puts the question. "Are the words of exclusion in this section so strong, when applied to the things to be paid for—namely, a tramway *in situ*—as to exclude the ordinary way of ascertaining present value?"

It must be borne in mind that the County Council can only acquire ownership rights under the sale. They can let, but cannot themselves use, occupy, or work the tramway. They are debarred from making occupiers' profits, and therefore it is most reasonable to provide that no allowance should be made for them in the sale. It is most fair that in a sale to a public authority "the then value" should not be run up by history of "past" or the anticipation of "future" profits. These words, "past or future," are suggested by the word "then." The provision is that no "allowance" is to be made, and that is very far from an enactment that "the then value" may not be ascertained according to the ordinary rule and practice in like cases. The argument of the respondents concentrates attention exclusively upon the parenthesis, and ignores and belittles everything in the section which would explain its terms. The *Lord Justice General* in his judgment well says: "The contention of the Corporation seems to me exposed to the grave objection that it allows words having a subordinate and qualifying position to kill the plain import of the main proposition to which they relate, and does so by ascribing to those words more meaning than, *primâ facie*, they bear. I cannot conceive why the Legislature should describe the transaction as a sale, and say the terms are to be the payment of the existing value of the tramway, and then incidentally and by way of exclusion put in words which make the terms inconsistent with sale and purchase, and inconsistent also with payment of existing value."

It must be remembered that "the then value" of lands and buildings has also to be measured under the same section, and it would be almost impossible to ascertain the value of land and buildings without considering what rent a tenant would pay for them. The land and buildings may have cost large sums, and no one could suggest the reasonableness of giving less than their fair value under this provision. No "allowance" is here to be made for "past or future profits," but "the then value" is to be arrived at by the ordinary methods.

It is also not to be forgotten that under this section a tramway company might be compelled to sell the most paying and successful part of its undertaking, retaining only the part which barely, if at all, pays its expenses. Under this section, admittedly, they could get no compensation for compulsory sale, or for severance. The company concede that they, under its terms, are debarred from "any allowance" for their profits in "the past" or their hope of greater profits in "the future"; but could it have been intended that in providing they were to get "the then value" they were to get less than would come to them under the ordinary rule, and be subjected to an arbitrary standard discovered by the arbitrator? The Kirkleatham case is important as showing (to quote *Mr. Justice Henn Collins*) "the words which the Legislature uses when it does intend that the thing sold and the thing paid for shall be the materials, and not the right to use the materials."

The section in the present case is framed in an entirely different manner, because, in my opinion, the Legislature contemplated a different operation with different results. No question of hardship can be considered. The construction of this section is all that is before your Lordships. I venture to think that the construction suggested by the County Council is unreasonable, and that it would be natural to expect that if the Legislature contemplated such a meaning they would have said so in plain language. The weighty words of *Mr. Justice Mathew* are worthy of attention:—"This Act of Parliament was intended to inform the public who were disposed to become shareholders in any undertaking of this sort, and one would expect plain language addressed to such persons and their advisers as to what Parliament meant. If Parliament meant to inform the public 'you shall not have, at the end of 21 years, compensation for the value of the undertaking, but the undertaking shall be sold and the materials *in situ*, less depreciation,' I cannot help thinking that very few tramways would have been constructed under these circumstances, because a shareholder proposing to take shares must satisfy himself that the profits of the undertaking would not only pay him interest upon his investment, but would restore to him wholly or partially, at the end of 21 years, his capital."

I have already intimated the doubts which I must entertain of the soundness of my views when I recognise the high authority of those who have reached a different conclusion, but, with all deference and submission, in my opinion the judgment appealed from should be reversed.

The judgment of the Court below was affirmed, and the appeal dismissed with costs.

THE LONDON STREET TRAMWAYS COMPANY *v.* THE LONDON COUNTY COUNCIL.

This appeal from a decision of the Court of Appeal involved a similar question. The appellants have, under the authority of their

Acts of Parliament, laid down and constructed tramways in certain streets of the metropolis, and work such tramways with cars and horses, and own or hold on lease various depôts in connection therewith. A large section of the tramways, being the tramways in question in this appeal, were constructed and worked under the powers of the London Street Tramways Act, 1870. By section 44 of that Act it was provided :—

> "The Metropolitan Board of Works may, if by resolution passed at a special meeting they so decide, within six months after the expiration of a period of twenty-one years from the passing of this Act, and within six months after the expiration of every subsequent period of seven years, or within three months after any order made by the Board of Trade under either of the two next preceding sections, with the approval of the Board of Trade, by notice in writing, require the company to sell, and thereupon the company shall sell to them their undertaking upon terms of paying the then value (exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory sale, or other consideration whatsoever) of the tramway and all lands, buildings, works, materials, and plant of the company suitable to and used by them for the purposes of their undertaking, such value to be in case of difference determined by an engineer or other fit person nominated as referee by the Board of Trade on the application of either party, and the expenses of the reference to be borne and paid as the referee directs; and when any such sale has been made all the rights, powers, and authorities of the company in respect to the undertaking sold, or where any order has been made by the Board of Trade under either of the next preceding sections, all the rights, powers, and authorities of the company previous to the making of such order in respect of the undertaking sold, shall be transferred to, vested in, and may be exercised by the Metropolitan Board of Works in like manner as if that Board had been authorised by this Act to construct the tramways and had been named in this Act instead of the company. No such resolution shall be valid unless a month's previous notice of the meeting and of the purpose thereof has been given in manner in which notices of meetings of such Board are usually given, nor unless two-thirds of the members constituting such Board are present and vote at the meeting, and a majority of those present and voting concur in the resolution, and it shall be lawful for the chairman of any such meeting, with the consent of a majority of the members present, to adjourn the same from time to time, and the Metropolitan Board of Works may, in order to raise money for the purpose of carrying this section into effect, create additional stock, not exceeding in the whole £300,000, under the Metropolitan Board of Works (Loans) Act, 1869, in like manner and with the like sanction in and with which they may create stock in order to raise money for the purposes of the Acts mentioned in the first schedule to that Act, and all the provisions of that Act shall apply as if that money were raised and that stock were created for the purposes of the last-mentioned Acts, with the exception that the money required for the purposes of this section may be borrowed by them in addition to the sum limited by section 38 of the Metropolitan Board of Works (Loans) Act, 1869, provided always that the Metropolitan Board of Works shall not under the powers of this Act and of any other Act passed in the present Session for the construction of tramways in the Metropolis and of the Tramways Act, 1870, create additional stock exceeding in the whole £300,000."

The respondents in this action, under the provisions of the Local Government Act, 1888, have succeeded to all the rights and duties of the Metropolitan Board of Works, including the rights conferred by the said 44th section. In pursuance of the said powers the respondents duly gave notice in writing to the appellants that the respondents required the appellants to sell to them the tramways and works and undertaking authorised by the London Street Tramways Act, 1870, and in pursuance of the said Act the Board of Trade duly appointed Sir Frederick Bramwell as referee to determine the value, exclusive of any allowance for past or future profits of the undertaking or any compensation for compulsory sale or other consideration whatsoever, of the tramways constructed under the authority of the said Act, and of all land, buildings, works, materials, and plant of the Tramway Company suitable to and used by them for the purposes of the undertaking authorised by the said Act.

In the course of the proceedings the appellants proposed to tender evidence of the actual profits made by them on the purchased tramways, and stated that the object of such evidence was to arrive at the value of the tramways by taking a certain number of years' purchase of the profits to be shown by such evidence. The respondents objected to such evidence on the ground that, having regard to the terms of the London Street Tramways Act, 1870, the referee was prohibited from taking past profits into consideration for the purpose aforesaid. The referee refused to receive such evidence on the ground that the terms of the said Act did not authorise or permit him to adopt a method of valuation based on years' purchase of profits.

Thereupon the appellants tendered further evidence to show the rental value of the purchased tramways considered as let or capable of being let to a tenant, and stated that the object of such evidence was to arrive at the value of the purchased tramways exclusive of any allowance for past or future profits of the undertaking. The respondents objected to such evidence, but the referee admitted the same, subject to such objection as might be taken on its being shown by cross-examination or further evidence that the proposed mode of arriving at a value by means thereof involved an allowance for past or future profits of the undertaking, and on such evidence and cross-examination being completed, and such objection taken, the referee abstained from taking such evidence into consideration in arriving at the value awarded, on the ground that the mode of valuation to which such evidence was directed involves an allowance for past or future profits within the meaning of the said section.

The respondents tendered evidence to show the opinion of expert witnesses as to the proper cost of construction of the purchased tramways and the depreciation of such value by comparing the condition at the time of sale and purchase with the condition when newly constructed, and stated that the object of such evidence was to arrive at the value on the basis of cost, less depreciation. The appellants objected to such evidence on the ground that evidence of the cost of construction, either with or without depreciation, was inadmissible for the purpose of ascertaining the value according to the true intent and meaning of the said section. The referee admitted such evidence as giving information which he might properly take into consideration in determining the value within the meaning of the said section under the circumstances aforesaid.

The referee, with a view to ascertain the value of the purchased tramways, measured by what would be the cost of establishing the purchased tramways as existing at the time of sale and purchase, required evidence of the cost of obtaining the Parliamentary powers necessary to authorise the construction and use thereof, and evidence relating to certain outgoings which in the course of the reference had been incidentally mentioned, and appeared to be outgoings of the kind necessarily or usually involved in the construction and establishment of tramways such as the purchased tramways, and some such evidence was given.

In the course of the proceedings an agreement was made between the appellants and the respondents as to the price to be paid by the respondents for such of the depôts of the appellants as the respondents required to purchase, and as to the separate valuations of the horses, cars, harness, and stable utensils, plant, machinery, tools, and other materials in such agreement more particularly described.

The referee having heard the evidence given on behalf of the appellants and the respondents respectively, and the arguments of their counsel respectively, duly made and published his award, dated the 11th day of March, 1893, by which he determined and awarded that the sum of £64,500 was the value of the purchased tramways and the works thereof, other than the works comprised in the before-mentioned agreement, exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory purchase or other consideration whatsoever, except the consideration of the value to the appellants or the respondents, measured by what it would cost either the appellants or the respondents to establish the purchased tramways if such tramways did not now exist, but taking into account a proper deduction in respect of depreciation.

The appellants gave notice of motion to set aside or to send back to the referee the award, and the motion was heard before the Divisional Court of the Queen's Bench Division, consisting of Mr. Justice Mathew and Mr. Justice Collins, in January, 1894. The learned judges, having taken time to consider, gave judgment in favour of the appellants, ordering the award to be remitted to the referee for reconsideration and redetermination, and the costs of the motion to be ultimately paid by the respondents. The respondents appealed from this judgment to the Court of Appeal, and their appeal came on to be heard before Lord Justice Lindley, Lord Justice Kay, and Lord Justice A. L. Smith, in March, 1894. The Court, having taken time to consider, gave judgment allowing the appeal, and discharging the order with costs of such appeal and of the Divisional Court. The company thereupon appealed to the House of Lords.

Sir R. Webster, Q.C., Mr. Cripps, Q.C., and Mr. H. Sutton appeared for the appellant company; and Mr. Finlay, Q.C., and Mr. Freeman for the London County Council. The case having been argued, judgment was reserved, and their Lordships now delivered formal judgment, dismissing the appeal with costs.

The LORD CHANCELLOR.—I have carefully considered the distinctions pointed out between this case and that in which judgment has just been delivered, but I think with those of your Lordships who heard the case that there is no such difference as to lead to a different conclusion.

LORD WATSON and LORD SHAND concurred.

LORD ASHBOURNE said that he differed from the rest of their Lordships in this as he had done in the previous case.

The judgment of the Court of Appeal was affirmed, and the appeal dismissed with costs.

APPENDIX B.

CAPITAL COSTS, RECEIPTS, EXPENSES, AND WORKING STOCK OF TRAMWAYS IN THE UNITED KINGDOM FOR THE YEARS ENDING 30TH JUNE, 1891, 1892, 1893.*

		Length of lines open for public traffic.	Number of horses belonging to the companies.	Number of locomotive engines belonging to the companies.	Number of cars belonging to the companies.	Total number of passengers carried.	Total capital expended.	Gross receipts.	Working expenses.	Net receipts.
		Miles.	Horses.	Engines.	Cars.	Passengers.	£	£	£	£
England & Wales	1891	768	22,884	537	3,296	448,251,111	11,536,494	2,741,723	2,116,753	624,970
	1892	750	23,306	492	3,239	463,137,946	11,235,074	2,841,325	2,300,223	541,102
	1893	761	23,653	522	3,327	476,928,832	11,418,828	2,904,026	2,298,573	605,453
Scotland	1891	84	4,107	19	423	82,426,901	1,378,320	452,151	335,259	116,892
	1892	84	4,284	20	426	82,145,667	1,359,234	448,150	354,879	93,271
	1893	86	4,356	20	429	82,095,160	1,399,355	444,438	347,482	96,956
Ireland	1891	111	2,021	23	348	34,943,466	1,247,836	235,812	178,917	56,895
	1892	112	2,109	22	355	36,394,933	1,275,926	241,956	198,254	43,702
	1893	113	2,216	21	342	39,265,517	1,285,969	257,631	191,391	66,240
Totals for United Kingdom	1891	963	29,012	579	4,067	565,621,478	14,162,650	3,429,686	2,630,929	798,757
	1892	946	29,699	534	4,020	581,678,546	13,870,234	3,531,431	2,853,356	678,075
	1893	960	30,225	563	4,098	598,289,509	14,104,152	3,606,095	2,837,446	768,649

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* See *ante*, p. 27.

APPENDIX C.

TOTAL WORKING EXPENDITURE ON ALL THE TRAMWAYS OF THE UNITED KINGDOM FOR THE YEAR ENDING JUNE 30, 1893.[*]

Items.	Working expenditure.	Per mile open.	Per cent. of total expenditure.
	£	£	Per cent.
Maintenance of way and works	188,461	196	6·64
Locomotive power . . .	122,776	128	4·33
Horsing, or animal power .	1,060,879	1,104	37·38
Repair and renewal of engines	54,099	56	1·90
Repair and renewal of cars .	123,306	128	4·35
Renewal of horses . . .	144,969	151	5·12
Traffic expenses	791,055	823	27·88
Direction and management .	82,970	86	2·92
Rent of tramways (offices, stables, and sheds) . .	47,978	50	1·68
Rates, taxes, and turnpike tolls	80,541	84	2·84
Compensation for personal injury	29,296	31	1·04
Legal and parliamentary .	9,374	10	·34
Sundry	101,742	106	3·58
Totals	2,837,446	2,953	100·00

[*] See *ante*, p. 48.

APPENDIX D.

MILEAGE LENGTH OF STREET RAILWAYS IN THE UNITED STATES OF AMERICA, WITH CAR-STOCK.

THE subjoined Table* shows the street-railway mileage opened, with the number of cars worked by horse, electrical, cable, and steam-power, in the several United States of America, for the year 1893, with totals for 1892 added for comparison. The mileage length is single track, one mile of double track being counted as two of single track, and switches in addition. The numbers of cars under the headings cable, electrical, and steam, include trail cars as well as motor cars:—

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* Adapted from *The Street Railway Journal*, January, 1894.

COMPARISON OF THE MILEAGE AND CARS OF STREET RAILWAYS IN THE UNITED STATES OF AMERICA, FOR THE YEARS ENDING DECEMBER 1892 AND 1893.

States and Territories.	Horse.		Electric.		Cable.		Steam.		Total.	
	Miles.	Cars.	Miles.	Cars.	Miles.	Cars.	Miles.	Cars.	Miles.	Cars.
Alabama	36	92	79	144	...	...	148	112	263	348
Arizona	5	4	5	3	...	...	...	...	10	7
Arkansas	38	85	35	95	...	...	5	1	78	181
California	231	700	251	403	156	650	49	75	687	1828
Colorado	7	7	163	327	30	232	15	4	215	570
Connecticut	107	417	72	158	...	...	...	...	179	575
Delaware	6	22	13	50	...	...	...	...	19	72
District Columbia	57	324	56	107	22	389	...	...	135	820
Florida	28	55	5	10	...	...	...	...	33	65
Georgia	34	89	213	306	...	...	28	27	275	422
Idaho	...	...	3	2	...	...	...	...	3	2
Illinois	338	3380	398	805	86	863	4	2	826	5050
Indiana	92	167	173	402	...	...	8	14	273	583
Iowa	34	56	232	431	7	34	18	19	291	540
Kansas	54	111	108	160	...	...	11	22	173	293
Kentucky	98	280	130	413	...	...	...	...	228	693
Louisiana	98	334	50	103	...	...	9	36	157	473
Maine	28	52	48	93	...	...	...	...	76	145
Maryland	59	293	110	207	37	809	2	4	208	743
Massachusetts	219	1968	616	2184	...	...	6	13	841	4165
Michigan	51	206	249	637	...	...	9	11	309	854
Minnesota	10	16	319	778	11	80	...	...	340	874
Mississippi	21	54	...	...	...	...	6	10	27	64
Missouri	28	183	324	1078	108	1113	22	31	482	2405
Montana	...	...	62	67	2	4	2	5	66	76
Nebraska	52	61	150	304	6	59	...	...	208	424
New Hampshire	22	50	24	30	...	...	...	...	46	80
New Jersey	167	669	202	500	1	2	8	15	378	1186
New York	629	4275	758	2215	39	408	12	36	1438	6934
North Carolina	5	7	30	53	...	...	7	7	42	67
Ohio	65	157	550	1785	44	322	4	8	673	2272
Oregon	7	8	91	173	8	23	31	39	137	243
Pennsylvania	522	1812	682	1278	70	324	4	6	1278	3420
Rhode Island	68	353	51	89	3	58	...	...	122	500
South Carolina	34	93	12	6	...	...	...	...	46	99
South Dakota	17	16	9	7	...	...	6	2	32	25
Tennessee	23	50	202	332	...	...	73	57	298	439
Texas	90	205	278	365	...	...	32	29	400	599
Utah	...	...	86	128	...	...	15	10	101	138
Vermont	10	19	5	8	...	...	...	...	15	27
Virginia	26	89	120	181	...	...	4	4	150	274
Washington	7	8	227	250	27	77	10	5	271	340
West Virginia	13	19	34	85	...	...	...	...	47	104
Wisconsin	23	33	230	419	...	...	12	9	265	461
Wyoming	5	11		...	...	...	...	...	5	11
Total 1893	3497	16845	7470	17233	658	4805	546	616	12174	39500
Total 1892	4460	19315	5939	13415	646	3971	620	658	11634	37274

APPENDIX E.

INTRODUCTION OF AMERICAN STREET TRAMWAYS INTO EUROPE.

BY CHARLES BURN, C.E.

THE American horse tramway for the conveyance of passengers through the streets of cities, though in use in the United States since 1855, was not introduced into England until 1860, nor on the Continent until 1861.

In 1860 the American, Mr. George Francis Train, with the co-operation of Mr. G. B. Bruce, Mr. James Samuel, and Mr. Charles Burn, civil engineers, and others, obtained permission of the parish vestries to lay down tramrails along the Kennington Road, from Westminster Bridge to Kennington Common, from Westminster Abbey along Victoria Street to Victoria Station, and from the Marble Arch to Notting Hill Gate, along the Bayswater Road. Registered companies were formed to carry them out, the capital of which was privately subscribed by Mr. Train and his friends.

The tramrail adopted was what was then known as the Philadelphia tramrail, being 5 inches wide, 3 inches of which was flat, with a raised flange on one side 2 inches wide and ¾ inch in height, the flat portion to be for the use of the ordinary vehicles. The gauge was 4 feet 8½ inches. The rail was fixed to longitudinal sleepers, resting upon cross ties, laid upon the substratum of the roadway.

This rail, having a flat portion which could be used by ordinary vehicles, was thought to offer great advantages to the public, and that less objection would be raised to laying it down in the public thoroughfares than the grooved rail, which could be used by the tramcars only; but it was soon found to be very objectionable. The horses of the ordinary vehicles slipped upon the flat portion of the rail, and the raised flange seriously obstructed vehicles crossing the tramway, causing breakage of the axles, &c., so that great opposition was raised by the owners of private carriages and other vehicles against the Tramways, leading to legal proceedings being taken against the Tramway Companies, the result being that the Companies were compelled to remove the rails and reinstate the roadways. Tramways were considered a nuisance and not adapted for London; so that by having adopted an unsuitable rail the introduction of tramways into London was delayed ten years.

Mr. Train also obtained permission at the same time from the local authorities at Birkenhead to lay down tramways in that town, the same rail being adopted as in London. The local street traffic not being there so large as in London, no great objection was raised there against the rail; so the Birkenhead tramway was allowed to remain. Afterwards Parliamentary powers were obtained by the Tramway Company, the old rail was supplanted by the grooved rail, and this tramway has been working ever since; so the Birkenhead tramway may be regarded as the first American tramway constructed and successfully worked in England.

Three years previously, or in 1857, a concession was granted by the French Government to a Monsieur Boyer Bardy to construct and work an American horse tramway from Clermont-Jerraud to Reom, in the Department of the Puy de Dome. This concession he transferred to Mr. Charles Burn, C.E., in 1859, who endeavoured to carry it out by means of an English company called "The Anglo-French Tram Railroad Company, Limited." This company was the first English tramway company registered in London. Attempts were made to raise the capital in London, but without success; so the project was abandoned and the concession lapsed. The *cahier des charges*, or conditions upon which this concession was granted, has been the model upon which concessions for tramways on the Continent since granted have been based.

In 1861 a concession was obtained by Mr. Charles Burn, C.E., for the construction and working of an American tramway in Switzerland, from Geneva to Carouge, a length of about two miles. The conditions upon which this tramway was granted were based upon the model of the Clermont-Reom concession, with this exception, that by reason of want of knowledge and experience on the part of the authorities as to the construction and working of American street tramways in Europe, and the effect upon other vehicles using the roadway, the concession was made a conditional one for five years only, at the end of which time, if the tramway was found to impede the ordinary traffic, or found to be a nuisance, the concessionaire was bound to remove it; if otherwise, the concession held good for another fifty years.

The tramway was constructed and opened by Mr. Burn in 1861, and proved a great success; so that within twelve months after the opening the concession was made definitive for fifty-five years.

This being the first American tramway constructed on the Continent, it attracted notice from all parts; so that within a few years concessions were obtained for tramways in Vienna, Hamburg, Copenhagen, and Berlin, and they are now found in most European cities, and have proved to be a great benefit to the inhabitants, and generally remunerative to the proprietors.

In England the tramway idea languished. It was ten years after Mr. Train's first attempt to establish tramways in London in 1860, that a second attempt was made. After the expenditure of many thousand pounds and against great opposition, an Act of Parliament was obtained by an Anglo-American Syndicate for the construction of tramways in North London.

APPENDIX F.

TRAMWAYS IN GERMANY: A COMPARISON BETWEEN THE COST OF HORSE-TRACTION AND ELECTRIC TRACTION.*

(Zeitschrift für Transportwesen und Strassenbau, 1893, p. 432.)

THE comparison is founded on many years' experience of an important German tramway company in horse-traction (the situation of which, however, is not given), and by carefully obtained trial-results in electric traction.

The tramway selected is 8·08 miles in length, and establishes intercourse between a large town and several suburbs. The time-table is so prepared that the trams run at 6.0, 6.30, 7.0 A.M., and then every quarter of an hour until 9 P.M., after which they run at 9.30, 10.0, 10.30, and 11 P.M. The car, which is a one-horse one, carries thirty persons inclusive of driver and guard; on twenty days of the year it is necessary to double this service.

With the use of horse-traction, a speed of eight to ten miles an hour is the limit, and eight cars are required for the service; 126 (2 × 63) single tours are made daily, and 1018·08 (126 × 8·08) car-miles are run, consequently 391, 961 [(365 + 20) × 1018·08] car-miles are run in the year.

As the daily performance of a horse in tramway work amounts, on the average, to 16 miles, theoretically 63 horses are required for the usual traffic, but in practice, 10 per cent. more are added to make allowances for disease and rest, so that 70 horses are kept. The 70 horses represent a capital of £3,150 (70 × £45), and a further sum of £4,250 is required for land and buildings. The following tables are then given as representing the yearly cost of horse-traction :—

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* For this paper the Author is indebted to the *Minutes of the Proceedings of the Institution of Civil Engineers*, vol. cxvi., session 1893-94, where it appears amongst the Foreign Abstracts.

I.—PAYMENT OF INTEREST AND DEPRECIATION.

	£	s.	d.
4 per cent. interest on £7,400 (£3,150 + £4,250)	296	0	0
15 ,, depreciation of capital value of horses	472	10	0
1½ ,, ,, ,, ,, buildings	63	15	0
Total	832	5	0

II.—COST OF MANAGEMENT.

	£	s.	d.
Salary of manager	90	0	0
Wages of eight drivers	360	0	0
Wages of six stable-boys	150	0	0
Provender for seventy horses	2,175	0	0
Harness and shoeing	287	10	0
Veterinary treatment	65	0	0
Repair of stables, &c.	100	0	0
Sundries	72	10	0
Total	3,300	0	0

These two sums, amounting to £4,132 5s. 0d. yearly for 70 horses, gives 3s. 2·8d. per horse per day. But to this sum is still to be added the hiring price of 63 horses for 20 days at 5s. per day, which amounts to £315. Therefore the total yearly disbursement for horse-traction is £4,447 5s. 0d., the cost per car-mile being 2·72d. $\left(\frac{£4,447\ 5s.\ 0d.}{391,961}\right)$.

The estimate for electric traction is founded on the overhead line system of O. L. Kummer & Co., of Dresden. Each car is provided with 2 electromotors of 8 H.P. The capital required is estimated as follows :—

	£	s.	d.
Land	150	0	0
Buildings	1,600	0	0
Boiler and engine and two dynamos, including all fittings	3,750	0	0
Length of 8·08 miles of line-work, fixed complete	3,500	0	0
Electric fittings for nine cars, one of which stands in reserve	2,250	0	0
Total capital expenditure	11,250	0	0

The following tables are then given as representing the yearly cost of electric traction :—

I.—PAYMENT OF INTEREST AND DEPRECIATION.

	£	s.	d.
4 per cent. interest on £11,250	450	0	0
1½ ,, depreciation on buildings account	24	0	0
7½ ,, ,, engine, &c., account	281	5	0
5 ,, ,, line-work account	175	0	0
15 ,, ,, electro-motors account	337	10	0
Total	1,267	15	0

II.—COST OF MANAGEMENT.

	£	s.	d.
Salary of manager	90	0	0
Wages for three enginemen	180	0	0
Fuel	830	0	0
Carriage of cinders	10	0	0
Lubricants	125	0	0
General repairs	225	0	0
Sundries	72	5	0
Total	1,532	5	0

These two sums, amounting to £2,800, give 1·72d. per car-mile as the cost of electric traction.

The paper concludes in enumerating several advantages that electrical cars possess over the horse-cars in the matter of speed, safety, and size in crowded streets, as well as in cost.

J. A. T.

APPENDIX G.

GAS MOTORS FOR TRAMWAYS.*

(By A. Kemper, Dessau, Journal für Gasbeleuchtung, 1893, p. 505.)

ONLY twenty-six years have elapsed since the first horse-tramway was established in Germany, but in 1889, in about fifty towns, there were 838 miles in use, while in the United States much greater progress has been made.

With horse-tramways, in addition to the heavy cost, there is the objection to the litter they create, especially at stopping places. The cost of horses for one-horse cars amounts to from 1·35 to 1·50 pence per car per mile, and twice as much for two-horse cars; but the cost of the motive power is small compared with the total cost, including veterinary surgeons, medicines, renewal of horses, shoeing, and repairing and cleaning the streets, all of which bring the total cost of working a one-horse tramcar to 4·5 to 5·4 pence per mile, or for a two-horse car 5·8 to 7·73 pence per mile. Horses have the advantage over other motors that they more easily overcome obstacles; experiments have shown that a horse, pulling a full tramcar, temporarily exerts more than ten times the nominal traction power. Horse-cars are also light, weighing only to 2 to 2½ tons, while the weight of a motor-car is 4 to 7 tons and more.

With steam-power there is not only the nuisance of smoke, ashes, and sparks, but also the disadvantage of weight and the general difficulty of working, and the working expenses are so heavy that steam can only be used advantageously when several cars are taken together. At Berne compressed air is used, compressed at a central station to 50 atmospheres, one horse-power being required to compress 148 cubic feet of air. The speed of the cars is about 7 miles per hour, which can be increased to over 9 miles per hour. A car weighs about 7 tons, and carries 20 passengers.

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* For this paper the Author is indebted to the *Minutes of the Proceedings of the Institution of Civil Engineers*, vol. cxvi., session 1893-94, where it appears amongst the Foreign Abstracts.

Cable-trams are suitable for steep gradients, but they can seldom be used in a town, as the cable must be enclosed, and passing places can only be worked with horses or supplementary cables. Hydraulic and also benzene and naphtha motors have also been proposed, and, in New York, trials have been made to utilise liquid carbonic acid. Electric motors have also been extensively adopted in America, and they are looked upon with much favour in Germany; but it has been found difficult to charge the accumulators on the cars.

For working tramcars with gas the receivers are six to ten in number, having a total capacity of 44 to 88 cubic feet, and are placed beneath the floor. The gas supply is taken from the mains, only a supply-station and a small compressing engine being needed; one or more such stations being provided, according to the length of the line, each station costing £400 to £600. A plan for a compressing-station is given, showing an 8-H.P. gas-engine with a compressor capable of compressing 2,130 cubic feet of gas per hour. The gas, taken from the main, is passed through a meter to two storage vessels, having a united capacity of nearly 400 cubic feet. At a pressure of 8 atmospheres they will supply the reservoirs of two cars at 6 atmospheres. The gas required for compressing purposes is about 8 per cent. of the gas to be compressed. Two types of cars for gas-tramways have been introduced in Germany. Those of Messrs. Guilliéron and Amrein are used on the line between Neuchatel and St. Blaize. There is an 8-H.P. gas-engine on the outside platform of the car. The gas receivers are sufficient for the double journey of over 3 miles each way, the consumption being estimated at 34 cubic feet per car per mile. An empty car weighs 6 tons, will carry 20 passengers, and costs £750.

The other type is that of Lührig of Dresden. Each car is driven by two 7-H.P. gas-engines, fixed under the seats, with the fly-wheels behind the backs of the seats. The engines can be worked together or separately, and arrangements are made for three rates of speed, 150 revolutions per minute when engines are running free, 200 revolutions for low and 240 for high speed. If the car remains only a short time at the stopping or end stations, the engines run alone, to avoid re-starting. Ignition is effected by means of a small electromagnetic lighter. The condensing-tanks are on the roof of the car, with automatic circulation. There are three shafts, one with toothed wheels worked direct from the engines and wheels for varying the speed. The large cars weigh when empty 7½ tons, and with 29 persons 9½ tons, and will ascend an incline of 1 in 23 at a moderate speed. A smaller car, better suited to steep gradients, has been constructed, and is worked with a 10-H.P. engine. This car weighs about 4½ tons, and holds 22 persons, and would ascend an incline of 1 in 15 at a speed of over 3½ miles per hour. The cost of a large car is estimated at £900, and of the smaller one at £700. The gas-consumption, with 10 to 12 passengers with the large car, was found to be 34·7 to 37 cubic feet per car per mile.

For the cost of construction it is estimated that, for a line about five miles long, with cars running every five minutes, which would require 20 cars, and with an average working day of 14 hours, the cost of a gas-worked tram-line, including rails, cars, buildings, &c., would be £6,040 per mile. Under similar conditions an electric tram is estimated to cost £7,648 per mile, and a horse-tram £5,636. The working expenses with gas at 3s. 5d. per 1,000 cubic feet are estimated at about 3 pence per car per mile, for horse-trams, with 1-horse cars at 4·25 to 5·4 pence per car per mile, and for electric trams at 3·86 pence per car per mile; and it is shown that, with similar traffic conditions, a gas-tram might be expected to give a return of 6½ per cent. on the capital invested, while an electric tram would barely cover the cost of working.

C. G.

APPENDIX H.

ELECTRICAL TRAMWAYS IN EUROPEAN COUNTRIES.

ACCORDING to Mr. Robert Hammond,* the following is a complete list of the electric tramways or railways in operation (June 1894), in Europe:—

Country and Town.	System.	Date of Completion.	Length of line (miles).	Total driving power (h.p.)	Method of transmission.
	UNITED KINGDOM.				
Portrush—Bushmills (Ireland)	Siemens	1883	6	100	Third rail
Blackpool...	Holroyd-Smith ...	1883	[illegible]	140	Conduit
Ryde Pier (I.W.) ...	Siemens	1883	¾	12	Third rail
Brighton	Magnus Volk ...	1884	1	20	Third rail
Bessbrook—Newry (Ireland)	Hopkinson ...	1885	3⅛	62	Third rail
Birmingham	Elwell-Parker ...	1890	3	80	Accumulators
Southend Pier	Crompton	1890	¾	50	Third rail
London (City and S. London Railway) ...	Hopkinson ...	1890	3½	1200	Third rail
Carstairs	Anderson-Munro	1891	1¼	50	Overhead
Leeds	Thomson-Houston	1891	5½	[illegible]	Overhead
St. Peter Port (Guernsey)	Siemens Bros. ...	1892	1¾	200	Overhead
Walsall, Wednesbury, Darlaston (S. Staff.)	Electric Construction Corporation	1892	7½	380	Overhead
Liverpool	Hopkinson ...	1893	6½	1600	Third rail
Douglas—Grondle Glen (I. of Man)	Hopkinson ...	1893	2½	100	Overhead

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* In a paper on "Electric Street Tramways," read at the Annual Meeting of the Incorporated Association of Municipal and County Engineers held in London 21st to 23rd June, 1894.

Country and Town.	System.	Date of Completion.	Length of line (miles).	Total driving power (h.p.)	Method of transmission.
	GERMANY.				
Lichterfeld (near Berlin)	Siemens & Halske	1881	2½	60	Overhead
Frankfort—Offenbach ...	Siemens & Halske	1884	4¼	160	Overhead
Halle	Sprague	1891 1892	4¾ 3	350	Overhead
Géra	Sprague	1892	5	525	Overhead
Bremen	Thomson-Houston	1892	7½	450	Overhead
Hanover	Siemens & Halske	1893	7¾	400	Overhead
Breslau	Sprague	1893	11	600	Overhead
Dresden	Siemens & Halske	1893	3¾	270	Overhead
Remschied ..	Thomson-Houston	1893	5¼	330	Overhead
Barmen	Siemens & Halske	1893	1	400	Overhead
Essen	Sprague	1893	7¾	400	Overhead
	AUSTRIA-HUNGARY.				
Mödling-Vienna ...	Siemens & Halske	1883	2¾	195	Overhead
Buda Pesth	Siemens & Halske	1889	12½	900	Conduit
Buda Pesth ...	Siemens & Halske	1893	3¼		Overhead
Lemberg	Siemens & Halske	1893	3¾	400	Overhead
Baden-Voslau ...	Schuckert... ...	—	3	60	Overhead
	BELGIUM.				
Liège-Herstal	Compagnie Internationale d'Electricité	1893	2	120	Overhead
	SPAIN.				
Bilbao	Thomson-Houston	1891	8¾	280	Overhead
	FRANCE.				
Clermont-Ferrand ...	Thury	1890	4¼	500	Overhead
Marseilles... ...	Oerlikon	1892	3¾	750	Overhead
Paris—					
Madeleine-Saint-Denis	——	1892	5½	375	Accumulators.
Opéra-Saint-Denis ...	——	1893	5½		
Salène	Compagnie de l'Industrie Electrique, de Genève	1892	3½	500	Overhead
Bordeaux—Bouscat ...	Thomson-Houston	1893	3	300	Overhead
	ITALY.				
Florence-Fiesole ...	Sprague and Thomson-Houston	1890	4½	250	Overhead
Genoa	Siemens & Halske	1892	1½	300	Overhead
Rome	Cattori	1893	⅜	130	Overhead
Milan	Thomson-Houston	1893	2	300	Overhead
	RUSSIA.				
Kiew	Sprague	1892	2	120	Overhead
	SWITZERLAND.				
Vevey-Montreuse ...	——	1887	6½	600	Overhead
Sirrch-Gelterkinden ...	Oerlikon	1891	2	40	Overhead
Grütsch-Mürren ...	Oerlikon	1891	2¾	150	Overhead
Orbe-Chavornay ...	Compagnie de l'Industrie Electrique, de Genève	1893	2⅓	130	Overhead
Stausstad-Staus... ...	Do.	1893	1	40	Overhead
	Totals ...	... ..	194½	14579	

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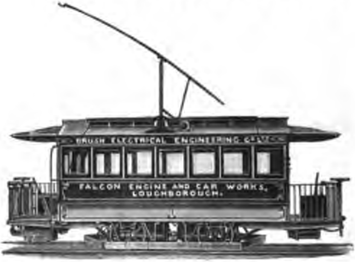
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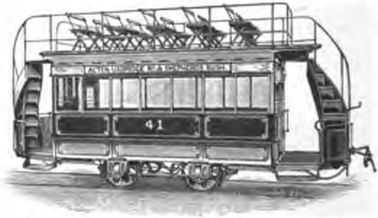

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